Vol. 13. No. 1 March, 1956

THE QUEENSLAND JOURNAL OF AGRICULTURAL SCIENCE

COMMONWEALTH ENTOMOLOGY LIBRARY
- 5 NOV 1956
Aus. HO

CONTENTS

PAGE.

Vitamin A in Poultry. A Survey of Liver Vitamin A Reserves in Fowls and Their Relationship to Diseases. By R. J. W. Gartner and J. W. Ryley 1

Sampling Fleeces to Estimate Yield of Clean Wool. By A. W. Beattie and R. E. Chapman 13

Wheat Investigations at Biloela Regional Experiment Station, Central Queensland. By G. H. Allen and R. W. George .. 19

Nodulation of Legumes Indigenous to Queensland. By G. D. Bowen 47

TECHNICAL NOTES.

Responses of Tropical Legumes to Inoculation. By G. D. Bowen 61

Tomato Mite Control. By W. A. Smith and G. W. Saunders 63

Painting Exposed Roots *in situ* for Photographing. By W. L. Parmeijer 67

PUBLISHED QUARTERLY

By the Queensland Department of Agriculture and Stock, Brisbane

Issued by Direction of Hon. H. H. COLLINS,
Secretary for Agriculture and Stock.

EDITORIAL BOARD.

Chairman and Editor: C. W. WINDERS, B.Sc.Agr.

A. L. CLAY, B.V.Sc., Assistant Director, Division of Animal Industry.

J. LEGG, B.Sc., D.V.Sc., M.R.C.V.S., Director of Research, Division of Animal Industry.

E. B. RICE, Dip.Ind.Chem., Director of Dairying, Division of Dairying.

J. H. SIMMONDS, M.B.E., M.Sc., Chief Pathologist, Science Branch, Division of Plant Industry.

W. J. S. SLOAN, M.Sc.Agr., Director of Agriculture, Agriculture Branch, Division of Plant Industry.

J. H. SMITH, M.Sc., N.D.A., Assistant Director of Horticulture, Horticulture Branch, Division of Plant Industry.

L. G. VALLANCE, M.Sc., Assistant Director, Bureau of Sugar Experiment Stations.

The Journal is supplied free of charge to organizations and institutions engaged in agricultural science or veterinary science. Application should be made to the Under Secretary, Department of Agriculture and Stock, Brisbane, Queensland, Australia.

THE QUEENSLAND JOURNAL OF AGRICULTURAL SCIENCE

VOL. 13. No. 1.
MARCH, 1956.

VITAMIN A IN POULTRY.

A Survey of Liver Vitamin A Reserves in Fowls and their Relationship to Diseases.

By R. J. W. GARTNER, B.Sc. (Analyst, Biochemical Branch, Division of Animal Industry), and J. W. RYLEY, B.V.Sc. (Chief Husbandry Officer, Animal Research Institute, Yeerongpilly).

SUMMARY.

The results of a survey of the vitamin A reserves in fowls in Queensland are presented. The fowls were those from commercial flocks submitted for diagnosis of various diseases. Liver storage of vitamin A was used as the criterion.

Livers of 313 fowls from 162 flocks were analysed. The average level of vitamin A found was 82 micrograms per gram of liver, with a range of less than 0.5 to 820 μg./g. Liver levels between 0 and 2 μg./g. were recorded in 16 per cent. of the fowls; 10.5 per cent. had liver levels between 2+ and 10μg./g.; and the remaining 73.5 per cent. had levels that were considered normal.

All fowls with pustules in the oesophagus had liver levels between 0 and 2 μg./g.

In the age group greater than 6 weeks there were 32 fowls with liver levels between 0 and 2 μg./g., of which 18 had lesions of vitamin A deficiency. In the age group up to 6 weeks there were 19 chickens with liver levels of the same order, of which only two showed similar lesions. It is considered, therefore, that liver analyses are a valuable diagnostic aid in the latter group, where definite pathological lesions occur infrequently.

There appeared to be no correlation between any of the diseases encountered and liver storage levels, except that there was a high incidence of vitamin A deficiency associated with ascaridiasis.

Liver levels in chickens under two weeks of age were much lower (29 μg./g.) than the average for all ages in the survey.

Newly hatched, healthy chickens from 10 hatcheries, with adequate vitamin A in the breeders' ration and good hatchability, showed a mean liver storage level of 19.7 μg./g.

I. INTRODUCTION.

Vitamin A is an essential requirement for poultry at all stages of life. A moderate deficiency causes retarded growth in chickens, and in adults decreased egg production with a fall in hatchability and lowered resistance to infections. A severe deficiency causes loss of condition and finally death, associated usually with a specific pathological picture in the adult, such as pustules in the oesophagus, " frosted " kidneys and distended ureters. It has been shown experimentally that fowls fed rations deficient in vitamin A have decreased resistance to coccidiosis (Murphy, Hunter and Knandel 1938, Taylor and Russell 1947) and to *Ascaridia galli* infestation (Ackert, McIlvaine and Crawford 1931, Seifried 1933).

Relatively few surveys on liver vitamin A levels of healthy or diseased fowls from commercial flocks have been undertaken. Holland, Satterfield and Gauger (1941) examined 85 fowls of all ages suffering from specific diseases and under various managements. They concluded that, with the exception of avitaminosis A, it was not possible to correlate any specific avian disease or internal parasitism with the liver vitamin A stores. Chichester, Russell and Hudson (1938) examined the livers from 154 diseased fowls and compared the results with those obtained from 69 healthy fowls from an experimental flock. They concluded that liver levels of vitamin A in fowls that died from specific diseases showed no significant relationship to the causative agent, the mode of transmission of the disease or the physiological system involved. Rubin, Bird and DeVolt (1941) examined 83 fowls from 25 commercial flocks in which poor growth, general poor condition and in some cases symptoms and lesions suggestive of borderline vitamin A deficiency were evident. They presented evidence to indicate the extent to which poor quality alfalfa (lucerne) may be responsible for vitamin A deficiency. Jungherr (1945), using nasal histopathology as the criterion of vitamin A deficiency, conducted a survey to determine the degree of vitamin A deficiency in commercial poultry flocks. He examined 354 fowls from 252 batches and concluded that there was no correlation between his criterion of vitamin A deficiency and the breed, sex or season or the principal disorders.

In our survey liver vitamin A concentrations were used as the index of the vitamin A status in the fowls for the following reasons. Sherman and Baynton (1926), Moore (1931), McCoord and Luce-Clausen (1934), and Baumann, Riising and Steenbock (1934) showed that in the rat 95 per cent. of the total vitamin A body stores is concentrated in the liver. Moore (1953) stated that under normal nutritional conditions the liver appears invariably to be the main site of storage of vitamin A in mammals and birds. Popper (1941) studied the histological distribution of vitamin A in the human body by means of fluorescence microscopy, and found a homogenous distribution in the liver. Guilbert and Hinshaw (1934), Holmes, Tripp and Campbell (1936), and Baumann, Semb, Holmes and Halpin (1939) have shown that the liver stores of vitamin A in fowls vary with their consumption of the vitamin.

Vitamin A analyses were done on the livers from some of the live fowls with various diseases submitted for autopsy to the Animal Research Institute, Yeerongpilly, Queensland, during the years 1952, 1953 and 1954. The levels found were used for a survey of the incidence of vitamin A deficiency in commercial flocks in Queensland. The relationship, if any, between liver storage of vitamin A and specific diseases was examined. Attention was also paid to the possible value of liver analyses as an aid to diagnosis in young chickens where the symptoms and lesions of vitamin A deficiency are indefinite. In addition, groups of newly hatched, healthy cockerels were selected at random and autopsied in order to obtain normal figures for their liver storage of vitamin A at hatching. The results are presented in this paper.

II. METHODS.

(1) Examination of Fowls.

Live fowls from commercial flocks submitted to the Animal Research Institute for routine diagnosis were used. Initially all fowls submitted from a flock on any one day were examined, but later the number was limited to two fowls from any one flock.

The fowls were killed by dislocating the neck and a complete autopsy was done. The liver was removed and the gall bladder dissected from the liver tissue. Care was taken to prevent bile from contaminating the liver. Each liver was analysed separately.

(2) Chemical Analysis.

The whole liver was prepared for saponification by weighing into a tared flask after cutting into cubes of about one centimetre. Sufficient aqueous 10 per cent. potassium hydroxide was then added to cover the sample. It was not always possible to proceed with the analysis immediately. Moore (1937) and Jensen and With (1939) showed that no appreciable deterioration of vitamin A takes place when liver is stored for a few days under these conditions.

The liver was saponified on a hot plate under reflux until completely disintegrated, which usually took up to one hour. The extraction procedure chosen was an adaptation of that used by Pierce (1945) for blood vitamin A. The saponified liver was made to a definite volume with distilled water. An aliquot was pipetted into a 100 ml. centrifuge tube and made up to 20 ml. with distilled water. For small livers weighing up to 1 gram the total saponification liquor was made up to 20 ml. with water and used for the extraction. Then aldehyde-free ethyl alcohol (20 ml.) was added, followed by 30 ml. redistilled petroleum ether (Shell X222). The centrifuge tube was stoppered and shaken for one minute. At intervals of five minutes it was shaken for two further periods each of one minute. The tube was then centrifuged for five minutes at an R.C.F. value of 1700.

An aliquot of the petroleum ether was pipetted into a photometer test tube of 2-centimetre light path and evaporated over a hot plate under a stream of carbon dioxide gas. The residue was immediately taken up in 2 ml. dry chloroform and two drops of acetic acid anhydride added. Nine millilitres of Carr Price reagent was then added from a fast delivery burette, the intensity of the ensuing blue colour being determined by measuring the transmittance at 620 mμ using a Lumetron photo-electric colorimeter as a direct reading instrument with a high-sensitivity multiple-reflection type galvanometer. The value obtained was read from a graph drawn up on U.S.P. vitamin A reference standard distributed by the Board of Trustees of the United States Pharmacopoeial Convention.

The use of the single extraction procedure with petroleum ether offers a more rapid method than the triple extraction and washing technique with sulphuric ether. Yudkin (1941) showed that petroleum ether gave incomplete extractions of vitamin A from saponified matter as compared with sulphuric ether. This is due to the concentration of fat present in the sample, and Gallup and Hoeffer (1946), working on vitamin A in sheep livers, found that petroleum ether is a suitable solvent provided that a soap equivalent of no more than 0·05 g. of oil is present in the 50 per cent. alcoholic solution to be extracted.

III. RESULTS.

(1) Survey of Commercial Flocks.

(a) General.

In most cases where two or more livers from fowls in the same age group and flock were analysed, the levels were found to be comparable whether deficient, marginal or normal. This is shown in the following cases :—

Flock.	Diagnosis.	Liver vitamin A μg./g.		
A	Vitamin A deficiency ..	<1	1·8	1·4
B	Nephritis	35	30	33
C	Respiratory disease ..	110	95	88
D	Rickets	500	600	400

It is thus considered that generally the analysis of livers from two fowls gives a reliable indication of the vitamin A status in any particular age group. There were, however, some exceptions : (a) where vitamin A supplementation had recently commenced after a deficiency had been diagnosed in the field ; (b) where grossly inadequate feeding space was provided ; and (c) where large numbers of *Ascaridia galli* were found in some fowls and not in others, the former having low and the latter normal levels. In a few cases no explanation was found for individual differences in the levels.

During the survey, livers of 313 fowls from 162 flocks were analysed. The average level of vitamin A found was 82 micrograms per gram of liver. The levels found in individual fowls varied from less than 0·5 μg./g. to 820 μg./g.

The grouping of results is shown in Fig. 1. These show that 16 per cent. of the fowls had liver levels between 0 and 2 μg./g., which we considered indicative of vitamin A deficiency. A further 10·5 per cent. had levels considered marginal (2 + to 10 μg./g.), and the remaining 73·5 per cent. had levels that were regarded as normal.

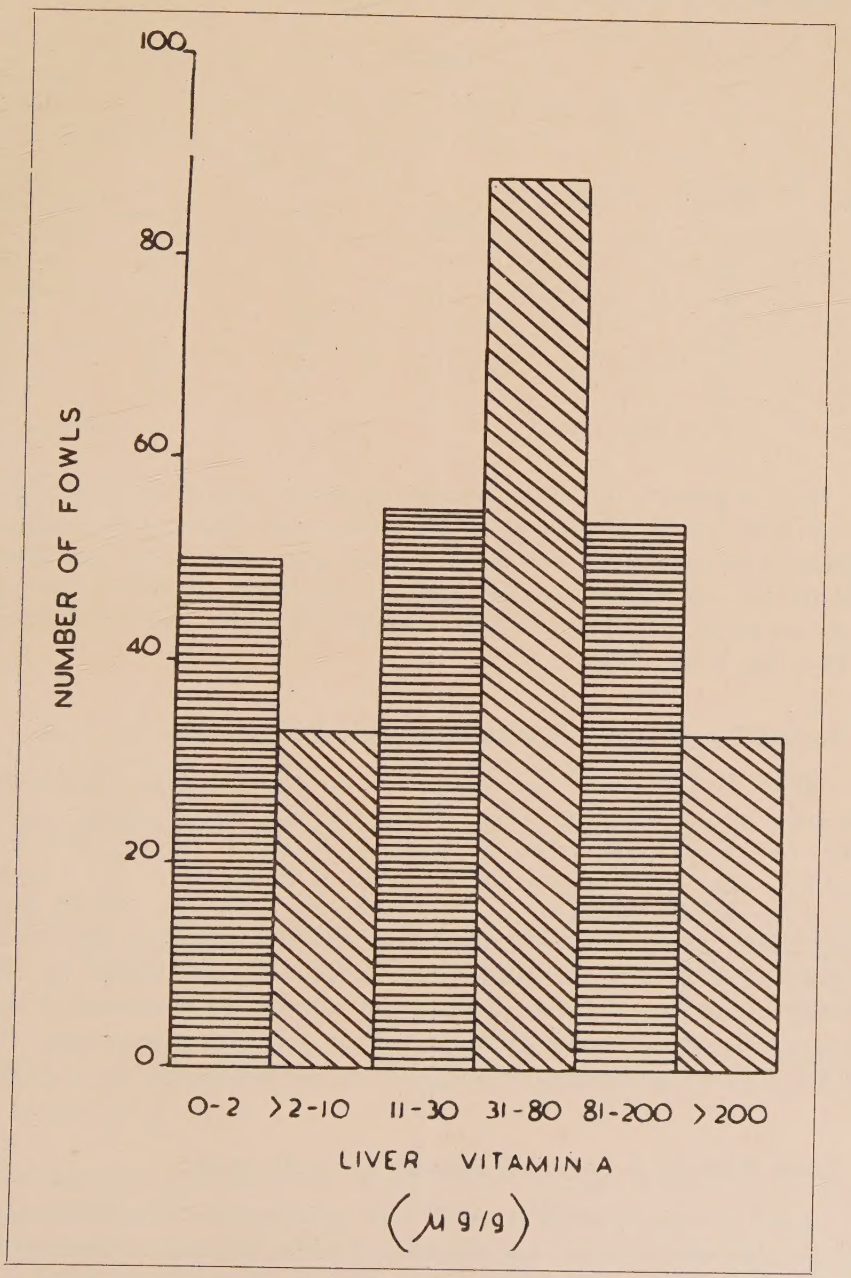


Fig. 1.

Distribution of liver vitamin A levels in the 313 fowls examined from commercial poultry flocks.

The liver vitamin A levels found in chickens up to 6 weeks of age are shown in Table 1. Of the 137 chickens, 19 had deficient vitamin A levels and of these only one 6-week-old chicken showed pustules in the oesophagus and one other kidney lesions. The liver vitamin A levels found in chickens under two weeks of age are lower than the average for the survey.

Table 1.

Liver Vitamin A Levels and Age of Chickens.

Age in Weeks.	Number of Chickens:	Number of Flocks.	Liver Vitamin A (μg./g.).			Number With Levels <10 μg./g.
			Minimum.	Maximum.	Mean.	
0–1	21	11	3	100	21	5
1–2	17	9	0·5	87	37	5
2–3	32	16	< 1	600	99	5
3–4	20	9	< 1	544	113	1
4–5	18	11	< 1	820	88	10
5–6	30	16	< 1	740	124	8

The age group of 0–6 weeks accounts for 44 per cent. of the total number of fowls analysed and for 38 per cent. of the incidence of vitamin A deficiency. The age group of 4½–6 weeks accounts for 12 per cent. of the total number analysed and for 26 per cent. of the incidence of vitamin A deficiency. Jungherr (1945) found that the age group of 5–16 weeks showed a significantly higher incidence of vitamin A deficiency than older fowls.

(b) Correlation of Analyses with Pathological Findings.

All of the 15 fowls showing pustules in the oesophagus had liver vitamin A levels between 0 and 2 μg./g. Five other fowls with kidney lesions, which were likewise considered to be typical of vitamin A deficiency, also had liver levels of this order. There were, however, 31 fowls with levels between 0 and 2 μg./g. not showing any definite lesions of vitamin A deficiency. In some of these fowls the feeding history or the symptoms observed in the flock suggested that vitamin A deficiency might have been a contributing factor in causing deaths. In others a deficiency might have remained undiagnosed without the assistance of chemical analyses. This applied particularly to chickens under 6 weeks of age. In fact, 17 of the 31 fowls not showing definite pathological findings were less than 6 weeks old.

(c) Liver Vitamin A Levels in Specific Avian Diseases.

Liver vitamin A levels found in fowls with specific diseases are shown in Table 2. Diseases such as spirochaetosis, visceral leucosis, histomoniasis, egg peritonitis and tumours are included, but they are not discussed because of the limited number of fowls involved.

Table 2.

LIVER VITAMIN A LEVELS FOUND IN SPECIFIC AVIAN DISEASES.

Disease.	Number of Flocks.	Number of Fowls.	Liver Levels 0 – 2 μg./g.	Liver Levels 2 + – 10 μg./g.	Liver Levels >10 μg./g.
Salmonellosis	4	7	0	2	5
Encephalitis	5	10	0	0	10
Nutritional encephalomalacia	16	29	3*	6	20
Rickets	6	12	0	0	12
Caecal coccidiosis	4	6	0	0	6
Intestinal coccidiosis—					
E. necatrix	8	16	1*	0	15
E. maxima	3	6	3	0	3
E. acervulina	3	6	2†	0	4
Fowl pox	9	19	1	4‡	14
Respiratory disease	26	61	10	3‡	48
Fowl cholera	3	5	0	0	5
Bluecomb	5	7	0	0	7
Nephritis (uraemia)	4	6	0	1‡	5
Leucosis	6	7	0	1‡	6
Ascaridiasis§	7	9	6	0	3
Avitaminosis A	12	16	16	0	0
Other diseases—					
Spirochaetosis	1	2	0	0	2
Visceral leucosis	1	1	0	1‡	0
Histomoniasis	3	3	0	0	3
Egg peritonitis	3	3	0	0	3
Tumours	5	6	2†	0	4

* Green feed as the only source of vitamin A supplement.

† Green feed as the only source of vitamin A supplement ; no supplement in the other.

‡ No data on the ration.

§ Ascaridiasis was diagnosed only when more than 25 *A. galli* were present.

Salmonellosis.—Of the seven chickens with this disease, two from the one flock had liver vitamin A levels of less than 10 μg./g. The other five had normal levels.

Encephalomyelitis.—This disease, as seen by us, is similar histopathologically to infectious avian encephalomyelitis, though not yet confirmed. All the liver vitamin A levels in this group were normal.

Nutritional encephalomalacia.—Normal liver vitamin A levels were found in 20 chickens (69 per cent.) in this group. Three chickens (10 per cent.) from one flock, where a carotene-containing foodstuff (grass or lucerne chaff) provided the sole source of vitamin A, had deficient levels. Six chickens (21 per cent.) from four other flocks had marginal levels.

Rickets.—All the 12 fowls in this group had rickets caused by a lack of calcium. The rations appeared adequate in vitamins A and D_3 and the liver vitamin A levels were satisfactory. Although rickets associated with a lack of vitamin D_3 sometimes occurs in Queensland, none was encountered in the survey.

Coccidiosis.—In Table 2 the disease has been divided into sections according to the principal species of coccidia found in the lesions. It was considered that, as beta-carotene is converted into vitamin A in the mucosa of the small intestine (Kon and Thompson 1951), the damage to the mucosa caused by the intestinal parasites might interfere with this conversion in cases where green feed was the main source of vitamin A.

The liver vitamin A levels found in the six chickens with caecal coccidiosis were all normal.

The levels found in cases of intestinal coccidiosis due to *Eimeria necatrix* varied. Of the 16 fowls in this sub-group only two had green feed as the sole vitamin A supplement and one of these was vitamin A deficient. All the 14 other fowls had access to fish oil supplements and their liver levels were normal.

Three of the six fowls with *E. maxima* had deficient vitamin A levels and were all from the same flock. No pustules or kidney lesions were found and the owner claimed they were fed recommended amounts of vitamin A concentrates in addition to green feed.

Of the six fowls with *E. acervulina* two were deficient—one had green feed as the sole source of vitamin A and the other no vitamin A supplement at all.

Fowl pox.—The 19 fowls in this group had the cutaneous form of this disease. Only one was vitamin A deficient and the feeding of the four fowls with marginal liver vitamin A reserves was questionable. The remaining 74 per cent. had normal liver levels.

Respiratory diseases.—This group includes fowls with infectious laryngotracheitis, respiratory fowl cholera, infectious coryza, a disease resembling chronic respiratory disease, and other fowls with respiratory symptoms in which the exact etiology was not determined. Livers of 61 fowls from 26 flocks were examined. Of these, 10 fowls (16 per cent.) from seven flocks were deficient in vitamin A.

Fowl cholera.—The five fowls in this group had the septicaemic form of the disease. The vitamin A levels found in the livers of all these fowls were normal.

Bluecomb.—All the seven fowls examined had normal liver vitamin A levels.

Nephritis.—This condition of unknown etiology has been described by Hungerford (1951) as uraemia and is characterised by swollen, pale kidneys difficult to distinguish from the " frosted " kidneys seen in vitamin A deficiency. However, the history of the outbreak, the symptoms and a lack of distension of the ureters aid in the diagnosis. One of the six fowls in this group had a marginal liver vitamin A level.

Leucosis.—The levels in the six fowls with neural leucosis only were all normal. The seventh fowl with both neural and visceral leucosis (not involving the liver) had a liver vitamin A level of 4 μg./g. No fowls with uncomplicated visceral leucosis were included in the survey. Gordon (1953) found that the majority of fowls affected with leucosis showed sub-normal vitamin A liver levels.

Ascaridiasis.—The nine fowls in Table 2 all had more than 25 *Ascaridia galli* and only three of these had normal liver vitamin A levels. Of three fowls from one flock, one with 50 *A. galli* was deficient in vitamin A, while the other two were free from worms of this species and had normal vitamin A stores.

(2) Liver Vitamin A Levels in Healthy Chickens at Hatching.

Lowered hatchability has been associated with low vitamin A levels in the ration fed to the breeding hens (Polk and Sipe 1940). To obtain normal figures for the liver storage of vitamin A at hatching, cockerels hatched in the one incubator from eggs obtained from 10 different hatcheries were selected at random and autopsied before they had eaten. Twelve cockerels from each hatchery were used and their livers bulked in groups of three, so that four analyses were done on each group. The vitamin A in the rations of the breeding hens from these hatcheries appeared adequate and the hatchability of the total number of eggs set averaged 75·4 per cent. (range, 68·1 – 82·6).

Table 3.

Liver Vitamin A Levels at Hatching in Chickens from Flocks with Good Feeding Histories.

Group.	Breed.	Liver Vitamin A (μg./g.).		
		Min.	Max.	Mean.
A	White Leghorn	17	23	21
B	White Leghorn	21	24	22
C	Australorp	18	24	21
D	White Leghorn	13	18	16
E	Australorp	14	21	18
F	Australorp	17	23	20
G	White Leghorn	21	27	24
H	Australorp	15	18	16
I	Australorp	13	20	17
J	Australorp-White Leghorn Cross	22	24	23

The results obtained in newly hatched, healthy chickens from these flocks with histories of good feeding are shown in Table 3. The results gave no evidence of any relationship between the liver vitamin A concentrations found and the hatchability. It will be noted that the levels found in all the 10 groups are of the same order, with a minimum of 13 μg./g., a maximum of 27 μg./g. and a mean of 19·7 μg./g.

These figures are comparable with those given by Castano, Baucher and Callenbach (1951) for chickens at hatching, namely 65 I.U./g. and 73 I.U./g. (21·7 μg./g. and 24·3 μg./g.)

IV. DISCUSSION.

In fowls, liver vitamin A levels between 0 and 2 μg./g. were considered indicative of vitamin A deficiency, these levels being largely supported by pathological findings attributed to avitaminosis A. Rubin, Bird and DeVolt (1941) chose 15 blue units per gram of liver (8·3 μg./g.) as the " low " point of vitamin A storage, this figure representing approximately half of the lowest concentration found in normal fowls. Arbitrarily, liver vitamin A levels between 2 + and 10 μg./g. have been chosen as marginal levels for this survey.

Of the 313 fowls examined from 162 commercial flocks, 16 per cent. were vitamin A deficient. This high percentage indicates that vitamin A deficiency is still a major cause of economic loss in commercial flocks in Queensland.

In cases of ascaridiasis there was a high incidence of vitamin A deficiency, where six out of the nine fowls examined showed deficient liver vitamin A levels. Seifried (1933) found that vitamin A deficiency increased susceptibility of fowls to internal parasitism. Ackert, McIlvaine and Crawford (1931) showed that fowls on a low intake of vitamin A were more susceptible to *Ascaridia galli* than those receiving an adequate amount. Our findings do not necessarily indicate inadequate vitamin A in the ration, as ascaridiasis is a condition which might be expected to interfere with the absorption and/or utilization of the vitamin. To support this, 50 *A. galli* were present in one of three fowls from a flock on adequate vitamin A supplements, but, whereas the two non-infested fowls had normal liver vitamin A levels, the one with ascaridiasis was deficient.

Seifried (1938) believed that vitamin A deficiency in fowls may favour increased susceptibility to respiratory diseases. The incidence of vitamin A deficiency in the 61 cases of respiratory diseases examined was 16 per cent., this being of the same order as found in the whole survey. Nevertheless, our findings do not necessarily disagree with those of Seifried, as many of the fowls with respiratory disease were examined after an outbreak had been in progress for some time and they may have been supplemented with vitamin A in an attempt to control the outbreak.

Davies (1952), examining 39 fowls infected with caecal or intestinal coccidiosis which were submitted for diagnosis, recorded liver vitamin A levels of 0–128 I.U./g. (0–42 μg./g.) with a mean of 6·9 I.U./g. (2·3 μg./g.). Ten experimentally infected fowls had levels of 2–38 I.U./g. (0·7–12·7 μg./g.) with a mean of 20·8 I.U./g. (6·9 μg./g.). Ten unaffected fowls from the same flock had normal reserves with a mean of 292 I.U./g. (97·3 μg./g.). In our survey there was no correlation between coccidiosis and vitamin A deficiency.

In fowls with intestinal coccidiosis, reliable data regarding green feed supplements as the only source of vitamin A are required to determine whether the lesions caused by the various species of coccidia inhibit the conversion of carotene to vitamin A through damage to the mucosa of the small intestine. These data are often difficult to obtain from owners. In Queensland most commercial mashes also contain some vitamin A concentrate. Therefore, in the limited number of fowls examined, no interpretation could be made of the relationship between intestinal coccidiosis and liver vitamin A levels where green feed was the only source of the vitamin.

Deficient liver vitamin A levels occured in all fowls where lesions, considered to be typical of vitamin A deficiency, were found at autopsy. It was mainly in the age group under 6 weeks that low liver vitamin A levels were found without a corresponding pathological picture. Thus liver analyses of chickens in this age group is a valuable aid in diagnosing vitamin A deficiency, which occurs as frequently in this group as in adults.

Livers of newly hatched chickens from 10 flocks with good hatchability and histories of good feeding had a mean value of 19·7 μg./g. Levels of this order in the livers of chickens at hatching would therefore appear to indicate adequate amounts of vitamin A in the breeder's ration.

The liver vitamin A levels of chickens at hatching are not as high as in the average adult fowl. Only after two weeks of age do their liver vitamin A concentrations build up to levels comparable with the average found in this survey. Further experimental work under controlled conditions is necessary before precise interpretations can be made of the vitamin A status in these chickens from their liver levels. The relationship of hatchability to the vitamin A concentration in the breeders' ration and to the vitamin A reserves in newly hatched chickens may be studied simultaneously.

V. ACKNOWLEDGEMENT.

Our thanks are due to officers of the Poultry Branch, Queensland Department of Agriculture and Stock, who submitted most of the fowls included in the survey and provided information on their feeding.

REFERENCES.

Ackert, J. E., McIlvaine, M. F., and Crawford, N. Z. 1931. Amer. J. Hyg. 13 : 320.
Baumann, C. A., Riising, B. M., and Steenbock, H. 1934. J.Biol.Chem. 107 : 705.
Baumann, C. A., Semb, J., Holmes, C. E., and Halpin, J. G. 1939. Poult.Sci. 18 : 48.
Castano, F. F., Boucher, R. V., and Callenbach, E. W. 1951. J.Nutrit. 45 : 131.
Chichester, D. F., Russell, W. C., and Hudson, C. B. 1938. Poult.Sci. 17 : 505.
Davies, A. W. 1952. Nature, Lond. 170 : 849.
Gallup, W. D., and Hoeffer, J. A. 1946. Industr.Engng.Chem. Anal.Ed. 18 : 288.
Gordon, R. F. 1953. Proc.Int.Vet.Congr. (Part II) : 385.
Guilbert, H. R., and Hinshaw, W. R. 1934. J.Nutrit. 8 : 45.
Holland, V. B., Satterfield, G. H., and Gauger, H. E. 1941. Poult.Sci. 20 : 543.
Holmes, A. D., Tripp, F., and Campbell, P. A. 1936. Poult.Sci. 15 : 71.
Hungerford, T. G. 1951. Diseases of Poultry. Angus and Robertson, Sydney.
Jensen, H. B., and With, T. K. 1939. Biochem.J. 33 : 1771.
Jungherr, E. 1945. Poult.Sci. 24 : 112.
Kon, S. K., and Thompson, S. Y. 1951. Brit.J.Nutrit. 5 : 114.
McCoord, A. B., and Luce-Clausen, E. M. 1934. J.Nutrit. 7 : 557.
Moore, T. 1931. Biochem.J. 25 : 275.
Moore, T. 1937. Biochem.J. 31 : 155.
Moore, T. 1953. Biochemistry and Physiology of Nutrition. Vol. 1. Academic Press, New York.
Murphy, R. R., Hunter, J. E., and Knandel, H. C. 1938. Poult.Sci. 17 : 377.
Pierce, A. W. 1945. Aust.J.Exp.Biol.Med.Sci. 23 : 295.
Polk, H. D., and Sipe, G. R. 1940. Poult.Sci. 19 : 396.
Popper, H. 1941. Arch.Path. 31 : 766.
Rubin, M., Bird, H. R., and DeVolt, H. M. 1941. Poult.Sci. 20 : 155.
Seifried, O. 1933. Muench.tierarztl.Wschr. 84 : 540.
Seifried, O. 1938. Berl.Muench.tierarztl.Wschr. 47 : 720.
Sherman, H. C., and Baynton, L. C. 1926. J.Amer.Chem.Soc. 47 : 1646.
Taylor, M. W., and Russell, W. C. 1947. Poult.Sci. 26 : 234.
Yudkin, S. 1941. Biochem.J. 35 : 551.

(Received for publication Dec. 7, 1955).

SAMPLING FLEECES TO ESTIMATE YIELD OF CLEAN WOOL.

By A. W. BEATTIE, B.Sc.Agr. (Assistant Biometrician, Sheep and Wool Branch, Division of Animal Industry), and R. E. CHAPMAN, B.Sc.App. (formerly of the Sheep and Wool Branch).

SUMMARY.

Fleeces from 85 Merino ewes and wethers were skirted, separated into 12 portions according to position, and scoured.

Yield of clean wool decreased from shoulder to rump, and the yields along the back were slightly higher than those on the sides.

The yield of all regions was highly correlated with that of the whole fleece and that of the skirted fleece, but the midside region is the most convenient sampling site.

I. INTRODUCTION.

Clean fleece weight is of primary importance in a programme of sheep selection which uses fleece measurement as an adjunct to visual appraisal. Various techniques have been reported for estimating the clean scoured yield of whole fleeces from small samples. The literature was reviewed by Pohle, Wolf and Terrill (1943), Pohle and Hazel (1944), and Pohle, Hazel and Keller (1945), while reporting their findings on suitable sampling sites. There is fair agreement among these workers that the midside and shoulder sites give the most accurate assessment of whole fleece yield.

Only two Australian references are known. Lockart (1954) studied the distribution of yields at different locations on 26 pelts from Merino ewes. He found that the coefficients of correlation between yields of small samples and the yield of a composite sample from the opposite side of the fleece were greatest for the shoulder-midside-hip area, being 0·91–0.94. Lang (1955) reported a correlation coefficient of 0·68 for the relationship between midside yield and unskirted whole fleece yield for 20 Merino sheep.

In the present study, unskirted Merino fleeces were divided into regions and scoured. The variation in yield in the different regions was examined, as well as the relationship between region yields and whole fleece yield.

II. MATERIALS AND METHODS.

Eighty-five unskirted fleeces, without belly wools, from 3-year-old Merino ewes and wethers on a south-eastern Queensland property were available.

The fleeces had been grown for a period of 12 months. Each was weighed, laid on a classing table, skirted and divided into 12 portions, A–L, as shown in Fig. 1. The regions A, B, C, D on the left side consisted of the neck, shoulder, midside and thigh wools respectively, while the corresponding regions on the right side were I, J, K, L. The wool along the back was divided into regions E, F, G, H, with F being adjacent to the midside regions C and K. In this subdivision, samples C and K were made approximately 100g. in weight, as is used for routine measurements in this laboratory. The other samples were slightly larger.

The skirtings from each fleece were divided into three portions for ease of handling in the small scour. They were later recombined to give a single estimate of the yield of the skirtings for each fleece. The whole fleeces were weighed immediately prior to subdivision, and the various portions immediately after subdivision.

The samples were scoured in a 4-bowl laboratory scour. After partial drying to a low moisture content, the scoured samples were held in an unventilated room to come to equilibrium with the air in the room. They were then weighed, and the moisture content determined by heating a number of samples to constant weight at 103°–106°C.

The samples were graded visually into groups of increasing vegetable matter content. The percentage of vegetable matter was determined on representative samples from each group by the method described by Lipson (1943).

The percentage of scouring residuals was determined on a number of scoured samples from each body region by Soxhlet extraction with a constant boiling mixture of benzol, alcohol and water. All yields were calculated as the percentage of bone-dry clean wool (free of vegetable matter and scouring residuals) in the greasy wool at the time of subdivision. The yields of the whole fleeces, skirted and unskirted, were calculated from the clean wool weights of the regions.

III. RESULTS AND DISCUSSION.

(1) Variation in Yield with Location.

The mean yields and standard deviations for the regions are shown in Table 1. This table is semi-diagrammatic and follows the lay-out of Fig. 1.

Table 1.

MEAN YIELD OF EACH REGION AND STANDARD DEVIATION OF EACH REGION YIELD.

D 60·9 ± 3·7		C 61·7 ± 3·6	B 61·9 ± 3·8	A 61·6 ± 4·1
H 61·0 ± 4·2	G 61·1 ± 4·0	F 62·2 ± 3·9		E 62·5 ± 3·9
L 60·7 ± 4·3		K 61·4 ± 3·8	J 61·8 ± 4·4	I 61·6 ± 4·2

Skirted fleece : 61·4 ± 3·4
Skirtings : 53·3 ± 3·8
Unskirted fleece : 58·3 ± 3·3

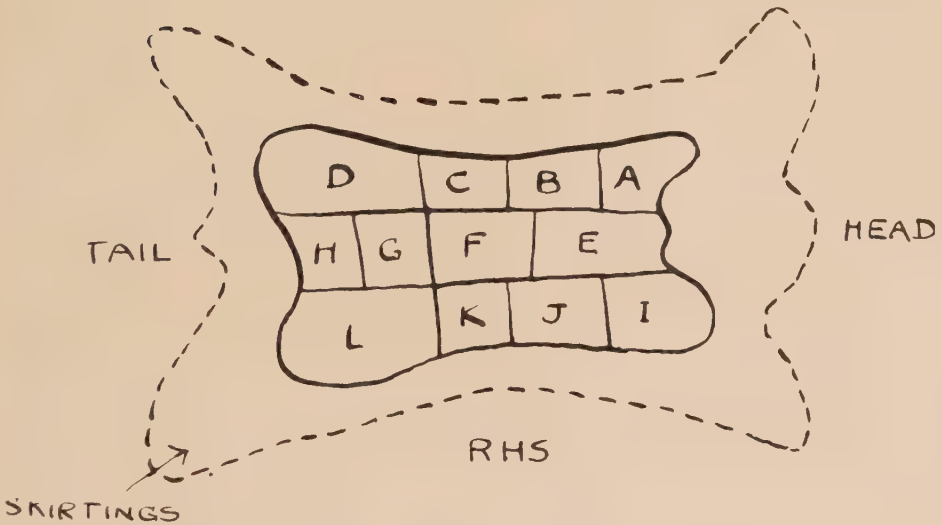


Fig. 1.
Diagram Showing Fleece Regions.

An analysis of variance of yields of the 12 regions of the skirted fleece is shown in Table 2.

Table 2.

ANALYSIS OF VARIANCE OF REGION YIELDS.

Source of Variation.	Degrees of Freedom.	Mean Square.	Component of Variance.
Between sheep	84	127·0*	10·1
Between regions ..	11	23·4*	0·2
Residual	924	5·3	..

* $P < 0.001$.

The variation in yield between sheep and the variation in yield between regions are highly significant. Two trends emerge from the results. The yields decrease from shoulder to rump and are slightly lower on the neck than on the shoulder. Lockart's (1954) results show a similar pattern. The yields along the back are slightly higher than those on the sides. This, however, does not agree with Lockart's findings. The different methods of sampling and environmental effects may be responsible for this. The property from which the samples in this study were obtained has an average yearly rainfall of about 28 inches. It is possible the wool along the backs of these sheep was somewhat leached by the relatively heavy rainfall. Also, the fleeces were carrying fairly large amounts of vegetable matter, particularly in the necks and lower regions.

There is also a tendency for each region on the left side to slightly outyield the corresponding region on the right side. The differences are very small and fall far short of significance, but it is of interest that the same feature is shown in Lockart's results. This has also been noted twice previously when samples have been taken from left and right midsides.

The individual results reveal that most of the differences are small and random, but occasional large differences favour the left-hand side more often than the right.

(2) Estimation of Whole Fleece Yield.

Table 3 shows the coefficients of correlation between the yield of each region and the yield of the whole fleece, both skirted and unskirted.

Table 3.

Correlation Coefficients and Regression Estimates—Sample and Fleece Yields.

Region.	Yield of Skirted Fleece and Yield of this Region.		Yield of Unskirted Fleece and Yield of this Region.	
	Correlation Coefficient.	Estimate.	Correlation Coefficient.	Estimate.
A	0·86	16·35 + 0·73A ± 1·73	0·80	17·25 + 0·67A ± 1·99
B	0·91	10·77 + 0·82B ± 1·44	0·85	11·92 + 0·75B ± 1·77
C	0·85	10·91 + 0·82C ± 1·79	0·77	13·36 + 0·73C ± 2·11
D	0·89	10·07 + 0·84D ± 1·52	0·84	11·24 + 0·77D ± 1·82
E	0·76	19·56 + 0·67E ± 2·22	0·74	18·48 + 0·64E ± 2·25
F	0·88	13·46 + 0·77F ± 1·62	0·87	12·14 + 0·74F ± 1·67
G	0·83	18·20 + 0·71G ± 1·88	0·77	19·28 + 0·64G ± 2·13
H	0·83	20·13 + 0·68H ± 1·89	0·77	20·82 + 0·61H ± 2·12
I	0·73	24·83 + 0·59I ± 2·34	0·64	26·93 + 0·51I ± 2·57
J	0·84	20·01 + 0·67J ± 1·82	0·79	20·47 + 0·61J ± 2·05
K	0·84	14·24 + 0·77K ± 1·84	0·78	15·54 + 0·70K ± 2·09
L	0·89	18·67 + 0·70L ± 1·59	0·82	19·49 + 0·64L ± 1·90
Skirtings Yield .	0·65	..	..	..

The regression estimates of whole fleece yield are also listed. Pohle and Hazel (1944), and Pohle, Hazel and Keller (1945) used the inverted regression in which whole fleece yield is regarded as the independent variable. In this study the view has been taken that the variates are subject to similar sources of error and that the situation can be appropriately represented by a normal bivariate distribution.

Regression estimates would, in any practical applications, be calculated from a random sample of a batch of fleeces and applied to the remaining fleeces. As an empirical approach, the regression of skirted fleece yield on left midside yield was calculated, using only 42 of the 85 available results. The prediction equation obtained was used to estimate the yield of the other 43 fleeces and led to the predicted standard error of estimate. If it is, however, thought that the inverted regression should be used, the estimates in Table 3 can be simply modified. In particular, the errors of estimate should be increased by a factor $\frac{1}{r}$, where r is the listed correlation coefficient.

Table 3 does not reveal any marked superiority of any other regions over the easily located midside portion. All regions lead to standard errors of estimate which would be regarded as acceptable for most purposes. The left side is very slightly superior to the right side, but the difference is so small that a much more extensive investigation would be required to test the significance of the difference.

(3) Estimation of Clean Wool Weight.

For this batch of samples there was very much more variation among fleece weights than among yields, and the relationship between greasy and clean wool weights of the unskirted fleeces was exceptionally strong (correlation coefficient = 0·95, standard error of estimate = 0·23 lb., mean greasy fleece weight = 6·93 lb.). Use of either midside yield would reduce the standard error of estimate to 0·16 lb.

IV. CONCLUSIONS.

The data presented show that the midside region of the fleece gives a good estimate of the yield of the whole fleece. Other regions are equally accurate but not perhaps so easily identifiable in the shearing shed. For this batch of samples the yield of the midside sample closely approximates that of the whole skirted fleece, but overestimates the yield of the unskirted fleece.

If the aim is to rank fleeces in order of yield, there is clearly no advantage to be gained from the use of a regression estimate which merely shifts the mean and multiplies the deviation from the mean by a constant amount. This is not the case when the yield is used to calculate clean fleece weight. However, the labour of scouring representative whole fleeces to obtain the appropriate prediction equation would only be warranted in exceptional circumstances.

V. ACKNOWLEDGEMENTS.

Thanks are due to Mr. R. G. Graham, "Columba," Gore, for making available the fleeces used in this study, and to Mr. C. J. Payne and the staff of the Wool Biology Laboratory of the Sheep and Wool Branch, Department of Agriculture and Stock, Brisbane, for their assistance in the yield determinations.

REFERENCES.

Lang, W. R. 1955. Correlation of clean scoured yield of mid-side and whole fleece wool samples. J.Aust.Inst.Agric.Sci. 21 : 103.

Lipson, M. 1943. A method for the estimation of vegetable material in scoured wool. J. Proc. Roy. Soc. N.S.W. 76 : 225–8.

Lockart, L. W. 1954. Sampling of fleeces for yield, staple length, and crimps per inch measurement. Aust. J. Agric. Res. 5 : 555–67.

Pohle, E. M., and Hazel, L. N. 1944. Clean wool yields in small samples from eight body regions as related to whole fleece yields in four breeds of sheep. J. Anim. Sci. 3: 159–65.

Pohle, E. M., Hazel, L. N., and Keller, H. R. 1945. The influence of location and size of sample in predicting whole fleece clean yields. J. Anim. Sci. 4 : 104–12.

Pohle, E. M., Wolf, H. W., and Terrill, C. E. 1943. Clean wool yield variation among regions of Rambouillet fleeces. J. Anim. Sci. 2 : 181–7.

(Received for publication Dec. 7, 1955).

WHEAT INVESTIGATIONS AT BILOELA REGIONAL EXPERIMENT STATION, CENTRAL QUEENSLAND.

By G. H. ALLEN, Q.D.A. (Agronomist) and R. W. GEORGE, Q.D.A. (Senior Experimentalist), Regional Experiment Stations Branch, Division of Plant Industry.

SUMMARY.

A review of climatic conditions has been given to show the relationship between the distribution of rainfall and the production of wheat in the Callide Valley region. Data have been presented to show the total amounts and the percentage chances of receiving specific quantities of rainfall during the fallowing, planting and growing periods for wheat.

Wheat for grain can be sown in most years and reasonable crops expected if sufficient stored water is available. If a minimum of 8 in. of effective fallowing rain has been received and wet soil is present to a depth of 48 in., good crops can be obtained with a planting rain of 1½ in. If only 4-8 in. of effective rain was received during the fallowing period, a planting rain of approximately 2 in. is desirable. In seasons where 4 in. of effective rain has not been received and most stored in the soil, it is not advisable to plant wheat irrespective of the amount of rain at planting time.

The utilisation of conserved moisture and rainfall by wheat during the years 1948-1951 has been studied and tables are presented to show the moisture loss from the soil at different depths during the cropping season. The overall use of water has been shown diagramatically and a ratio of water use to yield of grain has been established for each season of production. It was found that from 5 in. to 6·5 in. of available water could be stored in four feet of soil and that in all seasons the crop utilised most of the stored water as well as small amounts of current rainfall. The total use of water from the top 48 in. of soil was 6·77 in. in 1948, 6·53 in. in 1949, and 5·63 in. in 1951.

The availability of water affected plant behaviour. In 1951 the application of 2 in. of extra water by irrigation at flowering time increased yields by 5 to 12 bus. per acre for certain varieties. In 1950 high moisture conditions prevailed in conjunction with a high nitrogen status in the upper soil during the early growing season; the resultant bulky crop utilised such large volumes of water that the supply was exhausted before maturity was reached and the potential yield of grain was considerably reduced.

The wheat crop required approximately 1·5 in. of water to be readily available at flowering time to assure good grain yields. As roots are well distributed by that stage it is desirable that this water should be stored in the soil below three feet so that it is not utilised by earlier plant development, and this objective can be attained only by effective long-term fallowing.

The demand for and the importance of available nitrogen are high when the crop is in the grain-forming stage and it is considered desirable that a reasonable nitrate supply should be retained in the soil to meet this requirement. Production of nitrate can be fostered by cultural practices and crop rotations and storage may be achieved by holding some nitrate in solution with the water conserved at depth.

The efficiency of production under different seasonal conditions has been indicated by a ratio of water use to grain yield. For each inch of water used under the conditions of the experiments, an average yield of 5·5 bus. of grain per acre was obtained and as it was considered that some water was utilised from below the 48 in. depth of soil and not recorded, the actual figure may more closely approximate, 5 bus. of grain for each inch of water used.

Comments have been made on the selection of planting time and the suitability of varieties for grain and hay production. The influence of soil nitrogen supply and frosts upon wheat production in the Callide Valley has been discussed.

I. INTRODUCTION.

The expansion of grain growing in the main agricultural region of Queensland, the Darling Downs, has brought under cultivation most of the suitable land presently available for this purpose. Attention has therefore been directed in recent years to grain production in areas such as the Callide and Dawson Valleys and the marginal agricultural country of the Central Highlands.

In these newer areas of agricultural development, successful farming depends on the full use of the available knowledge of soils, soil moisture control, and soil conservation.

Experiments on crop growing have been conducted at the Regional Experiment Station at Biloela for 29 years. This report deals with the interpretation of the results of investigations related to wheat growing at that centre. In addition to a study of climatological records, the cultural practices, soil moisture relationships, and yields of different varieties of wheat are discussed in terms of the data accumulated at the Station.

II. LOCATION AND DESCRIPTION OF THE AREA.

Biloela is situated 102 miles in a southerly direction from Rockhampton. The Regional Experiment Station is two miles from the town and adjoins the Callide River.

The area is in the 25-30 in. per annum rainfall belt, with a summer precipitation approximately twice as high as that recorded during the winter months. Rainfall is somewhat erratic, with summer storms of high intensity and a dry August to October period when P/E values are unfavourable. Climatic data are shown in Table 1 as means of a 29-year period.

Table 1.

SUMMARY OF CLIMATOLOGICAL RECORDS FOR 29 YEARS AT BILOELA REGIONAL EXPERIMENT STATION.

—	Jan.	Feb.	Mar.	Apr.	May.	June.
Mean Rainfall (inches)	4·18	4·85	2·78	1·60	1·66	1·71
Mean Evaporation (inches)	9·19	6·93	7·39	6·11	4·71	3·51
Mean P/E Value	·45	·70	·37	·28	·35	·50
Mean Maximum Temperature (°F.) ..	91·6	89·1	87·6	83·0	77·0	71·3
Mean Minimum Temperature (°F.) ..	66·9	66·2	62·7	54·6	47·1	42·8
Number of Frosts	..	..	..	·2	1·7	6·2

—	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Mean Rainfall (inches) ..	1·27	0·61	0·96	2·00	2·88	3·29	27·79
Mean Evaporation (inches)	3·50	4·49	5·91	7·59	8·31	9·42	77·06
Mean P/E Value ..	·36	·13	·16	·26	·34	·35	..
Mean Maximum Temperature (°F.)	70·9	74·7	80·3	85·1	88·8	90·6	82·5
Mean Minimum Temperature (°F.)	40·1	40·6	46·3	54·8	60·5	64·3	53·9
Number of Frosts ..	10·0	7·7	1·4	·1	..	..	27·3

The region consists of alluvial plains approximately 15 miles wide bounded on each side and underlain by a series of Tertiary sediments, mainly clays, shales and sandstones. The basement of Palaeozoic rocks is largely volcanic, with some granite. The alluvial soils are usually fringed with Tertiary sediments on a slightly higher level with a scrub vegetation on grey and grey-brown clay or clay loam soils having a self-mulching surface horizon.

The Experiment Station is located on the alluvial flats, and although sandy loams occur near the stream banks the more extensive areas consist of deep dark-grey to grey-brown clay loams and clays. Soil profiles have resulted from banding in the alluvial flow, the fertility is high, and the structure is normally good. The wilting point of these soils varies from 10 to 17 per cent. in the top 24 in. and from 10 to 14 per cent. at lower depths. The moisture content at the field capacity level is 20-32 per cent. in the first 24 in. and from 18 to 24 per cent. in the deeper layers.

III. ANALYSES OF RAINFALL.

Records from the Experiment Station covering the period 1924-1952 have been examined. Although that period is comparatively short for critical analyses, the general trends are of value.

Mean monthly rainfall records, in groups covering the fallowing, planting and growing periods for wheat, are as follow:—

	Fallowing Period.					Planting Period.		Growing Period.			
	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
Mean rainfall over 29-year period (in.)	3·29	4·18	4·85	2·78	1·60	1·66	1·71	1·27	0·61	0·96	2·00

(1) Fallowing Rains.

The average rainfall during the growing period is inadequate to produce a crop of wheat and it is therefore essential to conserve in the soil the relatively good precipitation of the previous summer months. The average rainfall over the 29 years for the period December to April inclusive totals 16·52 in., but a number of factors significantly influence the amount which may be retained in the soil for later crop use. Many small falls which fail to penetrate below 12 in. are lost by evaporation; the rate of fall and nature of the soil surface may result in poor penetration and retention of moisture from the more common torrential rains of the summer period; and during the summer, weed growth draws considerable amounts of moisture from the soil.

(a) Effective Fallowing Rainfall.

Rainfall for each year has been totalled into effective fallowing falls wherein rain groups yielding more than 2 in. on consecutive days or in rainfall periods separated by up to three days have been tabulated. This grouping would be subject to reduction for runoff water, evapo-transpiration losses, &c. The mean monthly effective fallowing rainfalls are as follows:—

Dec.	Jan.	Feb.	Mar.	Apr.	Total.
2·06	2·74	3·94	1·84	1·10	11·68

Table 2.

Percentage of Years when Monthly Fallowing Rains Total Specific Amounts.

Month.	Mean of 29 Years.	Percentage Chance of Receiving Rain in Specific Amounts.					
		0–2″	2–4″	4–6″	6–8″	8–10″	10–15″
	Inches.						
December	3·29	28	43	25	..	..	4
January	4·18	28	28	14	20	7	3
February	4·85	17	31	17	10	17	7
March	2·78	51	20	15	15	..	..
April	1·60	69	24	4	..	3	..

The reliability of the summer fallowing rains have been examined and the percentage chances of receiving specific amounts of rain in fallowing months are presented in Table 2. A similar calculation has been made with regard to the effective fallowing rains which occurred in rain groups yielding over 2 in., and these data are shown in Table 3.

Table 3.

PERCENTAGE OF YEARS WHEN MONTHLY EFFECTIVE FALLOWING RAINS OCCUR IN SPECIFIC AMOUNTS.

Month.	Mean of 29 years.	Percentage Chance of Effective Rain Groups.				
		2–4″	4–6″	6–8″	8–10″	10–15″
	Inches.					
December	2·06	32	4	4	..	4
January	2·74	14	7	24	..	4
February	3·94	24	7	21	7	7
March	1·84	21	17	4	..	..
April	1·10	10	10	..	..	..

(b) Total Fallowing Rainfall.

The percentage chances of receiving specific amounts of total rain and total effective fallowing rain during the December to April period are shown in Table 4.

Table 4.

PERCENTAGE EXPECTANCY OF TOTAL RAINS AND TOTAL EFFECTIVE FALLOWINGS RAINS IN THE DECEMBER TO APRIL PERIOD.

Amount of Rain Group.	Expectancy of Total Rain.	Expectancy of Total Effective Fallowing Rain.
	%	%
Over 16 in. ..	36	18
12–16 in. ..	46	21
8–12 in. ..	14	29
4–8 in. ..	4	25
Under 4 in. ..	..	7

Effective fallowing rain of more than 12 in. was received in 39 per cent. of years, while more than 8 in. was received in 68 per cent. of years. As shown in Table 3, the greatest amount of rain is received during January and February, while March and April are progressively drier. A distribution of this type is quite suitable for preparing land for wheat. Provided the land is in a

Table 5.

Summary of Wheat Yields in Relation to Effective Fallowing Rains at Biloela Regional Experiment Station during a 28-year Period.

Group.	No. of Years.	Yield.	No. of Years.	Planting Rain.	No. of Years.	Growing Rain.	Comments.
Of 28 years where effective fallowing rain exceeded 8″ in Dec.-Apr. period in 19 years	12	Good ; over 25 bus.	11	Over 1½″	4	Over 6″	If over 8″ effective fallowing rain received, a good crop may be grown on planting rain of 1½–2″
					2	4–6″	
					5	2–4″	
			1	1–1½″	1	4–6″	
	3	Fair to good ; 18–25 bus.	2	Over 1½″	1	2–4″	
					1	Less than 2″	
			1	1–1½″	1	Less than 2″	
	2	Fair 12–18 bus.	1	1–1½″	1	2–4″	
			1	Less than 1″	1	Less than 2″	
	2	Nil	2	Nil			
Of 28 years where effective fallowing rain was 4—8″ in Dec.-Apr. period in 8 years	2	Good ; over 25 bus.	2	Over 2″	2	Over 6″	If effective fallowing rainfall is between 4″ and 8″, planting should only be made on over 2″ of rain in May or June.
	3	Fair to good ; 18–25 bus.	3	Over 2″	1	Over 6″	
					1	4–6″	
					1	2–4″	
	1	Fair ; 12–18 bus.	1	Over 2″	1	2–4″	
	1	Poor ; less than 12 bus.	1	1½–2″	1	2–4″	
	1	Nil	1	Nil			
Of 28 years where effective fallowing rain was less than 4″ in 1 year	1	Poor ; less than 12 bus.	1	1–1½″	1	2–4″	Do not plant on less than 4″ of effective fallowing rainfall, irrespective of the amount of planting rain.

14 years good .. .. 50·0%
6 years fair to good .. 21·5%
3 years fair .. .. 10·7%
2 years poor .. .. 7·1%
3 years not planted .. 10·7%

receptive condition for the higher rainfalls of January and February, a large percentage of the effective rain would be conserved, and general cultivation for weed eradication and seedbed preparation could be performed during March and April, when smaller falls of rain are received.

Over 4 in. of effective rain may be received in March in 21 per cent. of years and in April in 10 per cent. of years, and in the same number of years 2–4 in. can be expected. These falls would contribute materially to the moisture stored for later crop use. The records of high rainfall received in March or April generally signify a very late monsoonal influence and relatively dry conditions in the previous months of summer.

(c) Effect of Fallowing Rains on Yield.

In assessing the value of fallowing rains, the records of the Biloela Station have been examined. For most years data on wheat yields are available and for the other years an estimate of production has been made.

Yields have been recorded in four groups, viz.:—

(i.) Good—Over 25 bus. per acre.

(ii.) Fair to good—18–25 bus. per acre.

(iii.) Fair—12–18 bus. per acre.

(iv.) Poor—Under 12 bus. per acre.

Relevant details of rainfall during the planting and growing periods are shown for the respective years, with general conclusions, in Table 5.

(2) Planting Rains for Wheat.

During years when sufficient moisture has been conserved to wet the soil to a depth of 40–48 in., wheat could be sown dry in expectation of germinating rains or could be sown after planting rains are received.

Table 5 shows that planting rains of over 2 in. are required when only 4–8 in. of effective fallowing rain has been received in the summer, whereas a minimum of 1½–2 in. would be necessary if over 8 in. of effective fallowing rain was recorded. A good crop could be produced on 1–1½ in. at planting time if fairly good moisture status was maintained during the growing period.

It will be observed from Table 6 that the chances of planting rains are higher in May and June, but the month of July has been included for comparison even though a planting after the first week of July may result in later crop damage by early storms at the ripening stage.

The percentage chances of receiving certain amounts have also been given for groups of two and three months.

Table 6.

PERCENTAGE OF YEARS WHEN SPECIFIC AMOUNTS OF RAIN (AS A RAIN GROUP) CAN BE EXPECTED.

Amount of Rain Group.	Percentage of Years in Period —					
	May.	June.	July.	May-June.	June-July.	May, June, July.
½ in. or more ..	58·6	76·0	62·0	86·0	86·0	90·0
1 in. or more ..	45·0	58·6	34·5	76·0	76·0	86·0
1½ in. or more ..	38·0	31·0	20·7	58·6	48·3	72·4
2 in. or more ..	31·0	17·2	13·8	41·4	31·0	51·8
3 in. or more ..	10·4	13·8	10·4	20·7	27·6	31·0

The May-June combination is of most importance, and planting then should be possible in three out of four years with assurance of fair to good yields, provided adequate subsoil moisture has been conserved by fallowing over the previous summer.

Observations on the Experiment Station have shown that wheat planting before mid-May is particularly risky, as late frosts in August can cause heavy crop losses. In view of this hazard, the May rainfall has been examined to show the average falls during the first and second halves of the month.

In the first half of May, falls exceeded 3 in. in 6·9 per cent. of years; in 10·3 per cent. of years small falls of ½-1 in. were recorded. It would appear that early May is a period of light isolated showers with occasional heavy falls which may be due to monsoonal influences delayed from the preceding summer. The second half of May is more favoured, with reasonable planting rains (falls over 1½ in.) occurring one year in three. A summary of May rains giving percentage chances of receiving specific amounts is presented in Table 7.

Table 7.

PERCENTAGE CHANCES OF RECEIVING RAIN IN MAY AT BILOELA.

Amount of Rain Recorded.	Percentage Chance in Month.	
	First half of May.	Second half of May.
½ to 1 in. ..	10·3	13·8
1 to 1½ in. ..	..	6·9
1½ to 2 in. ..	..	6·9
2 to 3 in. ..	..	17·3
Over 3 in. ..	6·9	6·9

(3) Rain during the Growing Period.

The period July-September is the driest of the year, the mean annual rainfall for the three months being, respectively, 1·27, 0·61 and 0·96 in. In October, early storms are experienced, and although the amount of rain varies considerably from year to year the mean precipitation is 2·0 in.

The rains in early July are of value in assisting firm establishment of young wheat plants and maintenance of moist topsoil to encourage surface root development. Precipitation in August is of particular importance and even light falls may be utilised if a surface root structure has been developed. However, if crown rooting is not developed, August rains initiate this, so active growth, penetration of the soil and utilisation of future light rains which affect only the top few inches of soil will be possible.

It is considered that the value of light rainfall during the late growing and flowering period has frequently been underestimated in analysing wheat production.

An application of half an inch of water to bare land would penetrate approximately three inches on an average soil of the basin alluvials and therefore could not be conserved, but when falling on a growing wheat crop such a small amount could be effectively used if a surface rooting system had been produced.

The value of rain at flowering time, normally September, is of great significance. In 1951, yields were increased by up to 12½ bus. of grain per acre by a supplementary irrigation of 2 in. of water at flowering. The minimum amount that will cause a response in yield has not been determined, but it is likely that if earlier rain had induced crown rooting, then any rainfall exceeding 0·40 in. would be used to advantage and result in increased yields.

As the occurrence of rains during the growing period is highly important, an examination of the Biloela records has been made.

Rainfall groups have been tabulated into sections yielding 0·20-0·40, 0·40-0·60, 0·60-1·00, 1·00-2·00, and over 2·00 in. for each of the months July to October inclusive; the percentages of years in which specific amounts may be expected are shown in Table 8. Chances for periods of two months and three months are also given.

Table 8.

PERCENTAGE OF YEARS WHEN SPECIFIC AMOUNTS OF RAIN (AS A RAIN GROUP) CAN BE EXPECTED DURING THE WHEAT GROWING SEASON.

Amount of Rain Group.	Percentage Chance in Period.						
	July.	Aug.	Sept.	Oct.	July-Aug.	Aug.-Sept.	July-Aug.-Sept.
0·20–0·40 in. ..	28	34	38	31	41	62	69
0·40–0·60 in. ..	31	24	17	28	48	41	48
0·60–1·00 in. ..	14	24	10	14	31	28	28
1·00–2·00 in. ..	24	14	14	55	31	28	45
> 2·00 in. ..	14	..	10	24	14	10	21

It will be observed that in the period July-August-September more than 0·40 in. may be expected in at least one year in two, and that more than 0·60 in. could be expected in at least one year in three. The incidence of good rain is appreciably higher in July than in August or September, and the occurrence of heavier early summer rainfall in October is obvious.

As well as the number of years, the occurrence of two or more falls each month which would greatly enhance the value of light rainfalls must be considered. An examination of the data showed that in 31 per cent. of years there was more than one rain group in each of the three separate months July, August and September, and in October more than one rain group occurred in 62 per cent. of years.

The percentage of years in which multiple falls have been recorded for separate months and for grouping of months is shown in Table 9.

Table 9.

PERCENTAGE OF YEARS WHEN CERTAIN NUMBER OF RAIN GROUPS WERE RECORDED.

Number of Rain Groups.*	Period.						
	July.	Aug.	Sept.	Oct.	July-Aug.	Aug.-Sept.	July-Aug.-Sept.
1	55	38	38	21	17	28	10
2	21	31	21	45	38	24	31
3	10	..	10	17	24	21	14
4	..	..	..	..	10	14	10
5	..	..	..	..	3·5	3·5	24
6	..	..	..	..	..	..	10

* A rain group is defined as a rainfall period covering consecutive wet days and falls occurring at intervals of less than three days.

From the table it is obvious that reliance upon rains during the growing period is particularly risky. For wheat growing it is essential that sufficient conserved moisture be stored from the previous summer to produce a good crop and it is also necessary that planting rain should be adequate to ensure firm establishment of the young plants and linking of the surface and subsoil moisture to permit root expansion. However, as the percentage chances of receiving at least one fall in the 2-month groupings of July-August and August-September are 93 and 90, respectively, and two falls can be expected in these periods in 76 and 62 per cent. of years, the possibility of establishment and grain-forming rains is not to be disregarded.

IV. SOIL MOISTURE AND RELATIONSHIP TO WHEAT YIELDS.

(1) General Farming and Fallowing Practices.

The programme of operations at Biloela Regional Experiment Station is designed to trap and hold as much moisture as possible in the soil and to provide a suitable environment for nitrate-nitrogen production. It is necessary

to avoid over-cultivation, particularly with disc implements, with consequent destruction of soil structure and loss of permeability. Wastage of water must be overcome by limiting runoff and utilisation by weed growth.

If wheat is to follow wheat the stubble is ploughed as soon as soil conditions allow after harvesting, and when wheat is to follow another crop land preparation should commence not later than December. There is a natural sequence in the use of the various implements, aimed at opening the soil in the first instance, retaining a semi-rough condition for as long as possible, and gradually reducing the structure to a fine seedbed for a May or June planting. A typical series of operations is as follows:—

December—Disc plough or sundercut.

January—Harrow to take off roughness.

February—Tandem or offset disc if land is trashy or becomes weedy through prolonged wet weather. Avoid the disc and use the scarifier if this implement can be operated without choking.

March—A scarifier cultivation may be necessary to control weed growth.

April—The combined cultivator drill can be used in preference to the scarifier and after this working the land should be ready for planting.

May-June—Plant wheat after suitable rain with combine with light trailing harrows attached. Rolling to ensure germination is advantageous on certain soil types.

Minor variations are necessary according to seasonal conditions but a total of about six workings of the land can be anticipated.

(2) Data from Experiments.

Wheat varietal trials have been conducted at the Biloela Regional Experiment Station since 1948 and an examination of recorded data on moisture usage and crop yields has been made.

The crop-water relationships for certain years are summarised in the following pages, and tables showing the amounts of water available for crop use at various depths are included.

(a) Year 1948.

Area I.11-14. *Blocks* II, III *and* IV.

Wheat varieties were planted on June 30 on soil wet to a depth of 45-58 in.

Soil samples for moisture determinations were taken on July 1 and at varying intervals during the growing period of the crop. Determinations were made of the amount of available water* in the soil at each sampling at each depth. The water available is shown in Table 10.

Table 10.

Utilisation of Water by Wheat Crop, 1948.

Depth of Sample.	6″	12″	18″	24″	30″	36″	48″	Total Water Available.	Effective Rain.
	in.	in.	in.	in.	in.	in.	in.	in.	in.
Total available July 1	·92	·85	1·20	·97	·71	·58	·80	6·03	..
Rain July 3–6	..	..	..	..	..	..	..	..	1·40
Total available July 19	·90	·95	1·20	·97	·87	·53	·80	6·22	..
Aug. 3	·57	·82	1·02	·87	·70	·47	·87	5·34	..
16	·39	·57	·86	·73	·55	·41	·64	4·15	..
30	·22	·45	·53	·37	·30	·25	·75	2·87	..
Sept. 14	·18	·39	·38	·20	·08	·13	·61	1·97	..
30	·05	·32	·40	·16	·0	·0	·39	1·32	..
Nov. 10	·0	·20	·22	·12	·0	·0	·12	·66	..

Water used by crop .. 5·37 in.
Effective rain .. .. 1·40 in.
Total used .. .. 6·77 in.

It will be observed that the rainfall of 1·61 in. in July, of which 1·40 in. was estimated as effective, maintained the crop requirement for 12 days and allowed a small carryover in the 12-in. zone. Moisture loss from the 18-in. level was recorded in early August, and about six weeks after planting water was being drawn off from all depths. The demand on the water resources appears to be high in the 24-30 in. zone 10 weeks after planting, and this would coincide with emergence of the seedheads. The available water at 30 in. and 36 in. was exhausted by late September and the supply at 48 in. was being utilised.

The figures indicate that root penetration in these soils is particularly rapid. There is also a suggestion that roots in the 12-18 in. zone were not particularly active in gathering moisture in the later stages of plant growth in this season.

* Available water in inches has been determined by multiplying depth of soil (inches) by volume weight of soil by available moisture percentage (= measured water percentage — approximate wilting point), divided by 100.

$$\text{Inches of Water Available to Plant} = \frac{\text{Depth} \times \text{Volume Weight} \times \text{Available Moisture Percentage}}{100}$$

Wilting Point taken as 12% at 12 in., 13% at 18 in., 14% at 48 in.

Specific Gravity taken as 1·1 at 12 in., 1·2 at 24 in., 1·3 at 48 in.

The mean yield of the 10 varieties of wheat was 35·1 bus. per acre, which shows a relationship to use of water of 1 in. of water to 5·2 bus. of grain.

The use of water is shown diagramatically in Fig. 1.

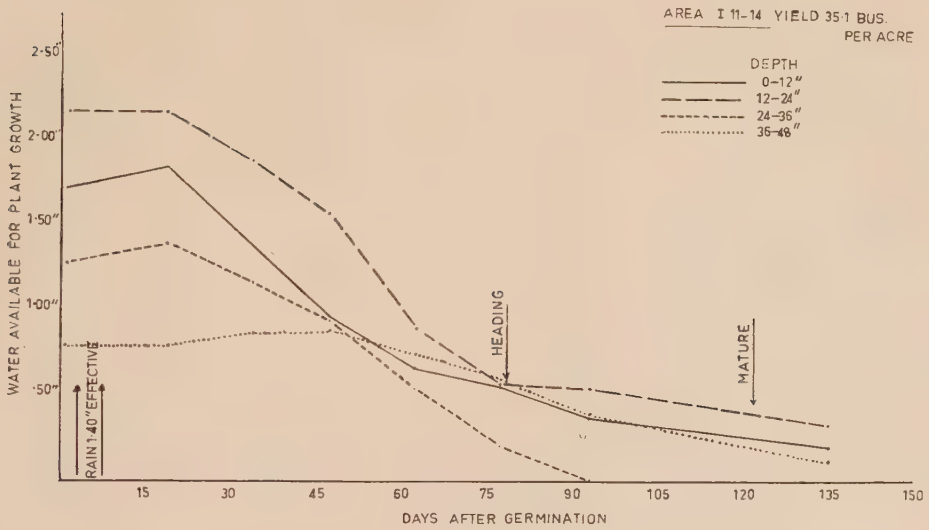


Fig. 1.

Diminution of Available Moisture in Top Four Feet of Soil During Growth of Wheat Crop, 1948.

Area I. 11–14. *Block I.*

Block I. was sown dry on June 10 and received rainfall totalling 3·48 in. on June 14–15; it has been estimated that 2·00 in. of rain was held in the soil. This crop germinated with approximately 6·72 in. of water stored in the soil and at harvesting time had utilised 6·28 in. plus 1·40 in. of effective rain received in July. The yield of this block was 43·1 bus. per acre, indicating a relationship of 1 in. of water to produce 5·62 bus. of grain.

The early planting evidently favoured this block and a heavy stand of plants was obtained. Results showed that water was being used from the 24 in. and 30 in. zones in eight weeks and that the 36-48 in. zone had been tapped before the crop was 10 weeks old.

(b) Year 1949.

Area J. 11–14.

A wheat varietal trial was sown on June 6 and soil moisture determinations were made during the growing season. The soil was wet to an average depth of 42–48 in. at planting.

The water available for plant growth from planting until early October, when heavy rains were recorded just as the crop was approaching maturity, has been set out for various periods in Table 11.

Table 11.

UTILISATION OF WATER BY WHEAT CROP, 1949.

Depth of Sample.	12″	18″	24″	30″	36″	48″	Total Water Available.	Effective Rain.
	in.	in.	in.	in.	in.	in.	in.	in.
Total available								
June 7 ..	1·64	·89	·77	·62	·66	1·08	5·66	..
July 8	1·58	·95	·78	·68	·72	·97	5·78	..
Rain July 19 ..	..	..	..	..	..	..	..	·60
Aug. 4 ..	·69	·45	·48	·47	·50	1·12	3·71	..
19 ..	·65	·37	·36	·30	·39	·97	3·04	..
Sept. 1 ..	·45	·29	·28	·12	·19	·64	1·97	..
Rain Sept. 11 ..	..	..	..	..	..	..	..	·60
15 ..	·35	·25	·20	·12	·13	·44	1·49	..
Oct. 6	Estimated use in 20 days (all depths) = ·66″					..	·83	..

Water used by crop	4·83 in.
Estimated use of Oct. rain by crop ..	·50 in.
Effective rain July and Sept.	1·20 in.
Total used	6·53 in.

During the first month after planting the use of water was very slight but in the second month the draw-off of water from the top 24 in. was fairly heavy, some two inches of stored water and over half an inch of effective rainfall being used. After two months the crop utilised water from the 30–48 in. zone and September growth was aided by 0·60 in. of effective rain.

Early wheats were approaching maturity by Oct. 6, when a rainy period extending to Oct. 16 yielded 3·81 in. This rain would have been of little value to the crop, and caused some germination in the heads of early-maturing varieties.

The results indicate that successful wheat yields can be obtained if adequate subsoil moisture is available for the crop after a planting rain, even if only light showers are recorded during the growing period. The yield of grain in 1949 from the crop of Puno where the moisture determinations were made was 37·5 bus. per acre, which indicates a ratio of yield to water use of 1 in. of water to 5·74 bus. of grain.

The periods of growth to full heading and maturity were very similar to those recorded in 1948.

The diminution of the available water supply is shown diagramatically in Fig. 2.

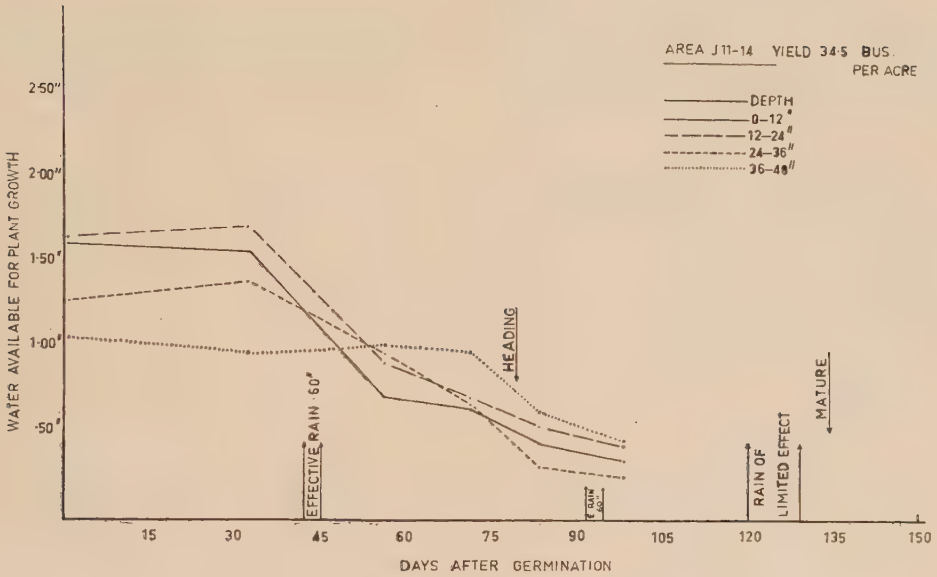


Fig. 2.

Diminution of Available Moisture in Top Four Feet of Soil During Growth of Wheat Crop, 1949.

(c) Year 1950.

Area I. 5–10.

In 1950 insufficient soil moisture determinations were made to allow a calculation of the type presented for previous years. It was an exceptionally wet season, heavy rains in January, February and March being followed by good falls during April, May and June. Stored water was available to a depth of 40 in. at planting on June 2. Over 2 in. of rain had been received during the third week in May and a further 1 in. was registered six days after planting. Light showers totalling 1 in. were received later in June and 2·82 in. spread over 16 days was received in July.

Early growth of the wheat was rapid and inclined to be lush under the high moisture conditions, and tall sappy plants were produced. The August rainfall, with two groups yielding 0·48 and 0·81 in. respectively, was inadequate to maintain the tall crop and by Sept. 5 most of the available moisture in the top 30 in. of soil had been utilised.

It is reasonable to assume that under the conditions of early growth, root concentration was confined to fairly shallow depths while ample moisture was present and that the crop grown under luxury conditions was unsuited to the drier conditions that existed during late August and September. Most varieties came into head at the end of August and the demand for water for head formation while maintaining very tall leafy plants could not be met.

The check in supply of readily available moisture during September appears to have been most significant in reducing the potential grain yield. The nitrate status may have also restricted yield, as leaching of nitrate-nitrogen undoubtedly occurred during the wet period of the summer.

Excessively wet conditions immediately after planting produced leafy succulent plants which evidently utilised a considerably greater amount of moisture and failed to develop a deep active root system. When a period of slight moisture stress occurred in September, coincidental with formation of grain, the physiological resources of the plants were not capable of active production of grain while maintaining the great bulk of other plant material. (In 1950 the mean height of the wheat was 50·7 in., or 19·2 in. higher than the 1949 crop).

Satisfactory yields averaging 36·4 bus. per acre were obtained, but it has been estimated that 10·30 in. of water was utilised, which gives a ratio of 1 in. of water to 3·43 bus. of grain.

The crop was ready for harvesting after mid-October but harvesting was delayed until three weeks later, when many of the varieties had lodged. The loss of grain was reported to vary from 2 bus. to 4 bus. per acre; hence a total yield of 39 bus. per acre may be assumed. The allowance for lost grain would raise the ratio of water use to crop yield to approximately 1 in. of water to 4 bus. of wheat. This rate of efficiency is considerably lower than in previous years and indicates that continuance of flush conditions until maturity would have been necessary to obtain yields proportionate to the quantity of water used.

Under the favourable conditions of early growth the varieties took approximately 10 days longer to come into full head and to reach maturity than in the 1948 and 1949 seasons.

(d) Year 1951.

Area J. 11–14.

This area was prepared for wheat following Poona pea in 1950-51, and soil moisture was present from the January and February rains. Planting rains were not received during May and June. Wheat was dry sown on June 29, and a 2 in. irrigation applied by sprays from July 3 to July 6, but due to very windy conditions an uneven watering was obtained. A further 2 in. of water was applied from July 11 to July 13, which connected up with stored moisture and assured a wet soil to a depth of more than 48 in.

Good germination was reported and the crop grew uniformly during August.

Soil moisture samples taken 13 days after irrigation indicated a high moisture status to 48 in. When the crop germinated, approximately 6·28 in. of water was available in the top 48 in. The rate of utilisation may be followed in Table 12.

Table 12.

UTILISATION OF WATER BY WHEAT CROP, 1951.

Depth of Sample.	6″	12″	18″	24″	30″	36″	48″	Total Water Available.	Effective Rain.
	in.	in.	in.	in.	in.	in.	in.	in.	in.
Water available at germination July 13	..	..	..	..	..	..	..	6·28	..
Available July 26 ..	·81	·72	·82	·75	·63	·65	1·40	5·78	..
Rain Aug. 21	..	..	..	..	..	..	..	..	·60
Available Aug. 24 ..	·51	·59	·60	·59	·62	·84	1·40	5·15	..
Sept. 14	·72		·38	·35	·34	·44	1·17	3·40	..
Rain Sept. 25 ..	..	..	..	..	..	..	..	..	·41
Available Oct. 2 ..	·36		·24	·19	·15	·20	·64	1·78	..
Oct. 26	·07	·20	·26	·17	·16	·22	·58	1·66	..

Water used by crop .. 4·62 in.
Effective rain .. .. 1·01 in.
Total used .. .. .. 5·63 in.

Soil moisture was not being utilised from the 30 in. zone by Aug. 24, about five weeks after germination. However, ample water had been available in the upper levels and considerable use had been made of the water stored to slightly below 24 in. By mid-September the moisture in the upper 24 in. had been almost depleted and the crop was drawing heavily on the 30–48 in. zone. The growing period was particularly dry and only two small falls of 0·60 and 0·41 in. of effective rain were recorded. These showers would have influenced the moisture status of the top 6in. of soil and crown root activity was observed after the first fall. These roots would have utilised the light September fall of 0·41 in.

The moisture studies were made on plots sown to Pusa 4 variety, which came into full head 75-78 days after germination, which is somewhat quicker than usual in this district. (The July planting has indicated that wheat sown late can utilise water with slightly greater efficiency, and that heading and maturity may occur earlier than if sown in May or June.) The quick-maturing varieties appear to utilise water more effectively than long-term varieties, especially in seasons of somewhat limited supply.

The yield of grain from Pusa 4 was 31·7 bus. per acre, which when compared with water used by the crop showed a ratio of 1 in. of water to 5.62 bus. of grain. It is highly probable that during the 1951 season water was used from below the sampling depth of 48 in., and if 1 in. of water was obtained the crop produced 4·8 bus. for each inch of water.

The use of soil moisture during the growing period is illustrated in Fig. 3.

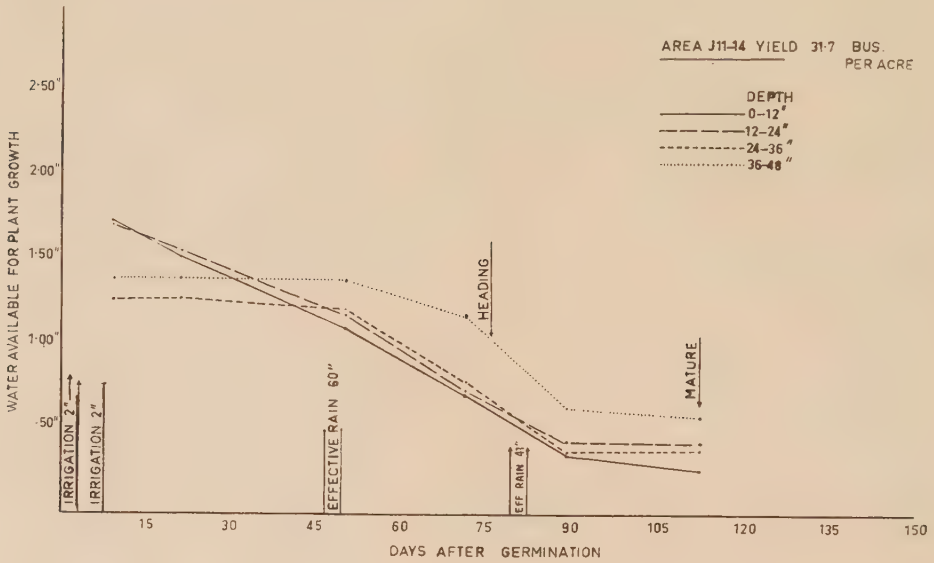


Fig. 3.

Diminution of Available Moisture in Top Four Feet of Soil During Growth of Wheat Crop, 1951.

(3) Application of Water at Flowering Time.

It was shown that in 1950 the flush growth of wheat under high moisture conditions utilised such large volumes of water in maintenance of vegetative material that the supply was exhausted before the crop reached maturity. To check on the significance of rainfall or irrigation at flowering time, a 2 in. irrigation was given on Sept. 25-26 to all plots in Blocks II and IV of the 1951 trial. This was approximately five days after Pusa 4 came into full head and the final increases in yields were not as high as those recorded for varieties which were just coming into full head when the water was applied. It may be that a similar application of water applied a week earlier on Pusa 4 would have promoted even higher yields than those recorded.

The plots that had been watered on Sept. 25-26 were sampled on Oct. 2. At this sampling the irrigated blocks contained 1·01 in. more available water in the top 48 in. of soil than the unwatered blocks, and this moisture was rapidly used by the crop. The figures show that little change in the moisture status of the lower depths occurred for some 2-3 weeks after the irrigation, indicating that the crop used the irrigation water which would have been retained in the top 12 in. of soil.

In this experiment, Pusa 4 which received the 2 in. irrigation yielded 5·4 bus. per acre more than the same variety in unwatered blocks. Varieties which were just coming into full head when the irrigation was given outyielded the unwatered blocks by up to 12·5 bus. per acre. It was reported that the irrigation applied at flowering time delayed maturity for 4-8 days, depending upon variety. The changes in soil moisture during the growing season are illustrated in Fig. 4.

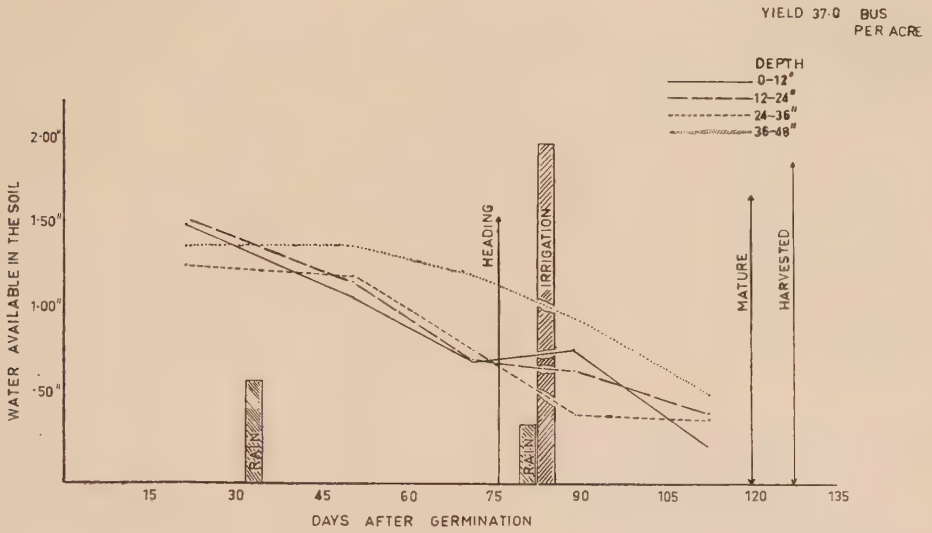


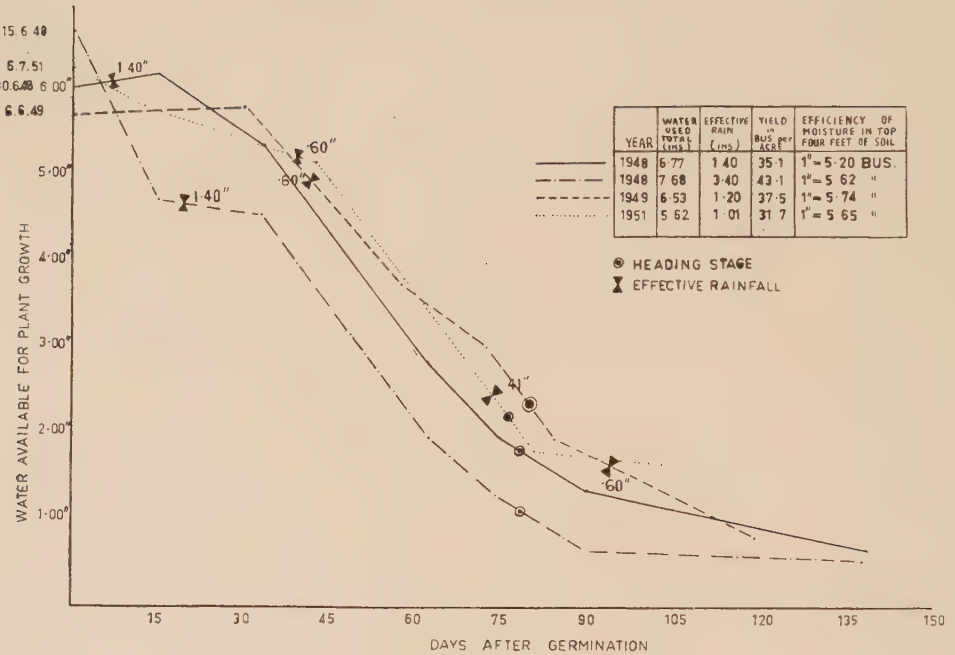
Fig. 4.

Use of Water by Wheat from Various Depths in 1951. The graph shows also the effect of a 2 in. irrigation applied at flowering.

The yield increases due to irrigation at flowering time were significant and a detailed study of grain and spikelet formation of certain varieties was undertaken. This study showed that the number of spikelets per head had not increased but that the number of grains per head and per spikelet accounted for most of the increased yield. The presence of a greater number of spikelets with three grains accounted for most of the increase in grains per head, and the grain from irrigated plots was slightly heavier than grain from the same varieties in blocks which did not receive additional water at flowering time.

(4) Comments on Moisture Utilisation.

In Fig. 5 the use of water from the soil by wheat is shown for each season. The rates of diminution of available moisture are very similar once the initial establishment of the plants is complete. In seasons where a large amount of moisture was present in the surface soil at germination and the soil had a high nitrogen status, the growth of plants was particularly rapid. It is possible that in some seasons a crop which commenced under such conditions would exhaust the available supply of water before reaching maturity.



YEAR	WATER USED TOTAL (INS.)	EFFECTIVE RAIN (INS.)	YIELD IN BUS. PER ACRE	EFFICIENCY OF MOISTURE IN TOP FOUR FEET OF SOIL
1948	6·77	1·40	35·1	1" = 5·20 BUS.
1948	7·68	3·40	43·1	1" = 5·62 "
1949	6·53	1·20	37·5	1" = 5·74 "
1951	5·62	1·01	31·7	1" = 5·65 "

Fig. 5.

Diminution of Available Moisture in Top Four Feet of Soil During Growth of Wheat Crops in Four Seasons.

The diagram indicates that between 1·1 and 2·3 in. of available water was still present at flowering time on the occasions studied and it is considered that this finding provides the clue to successful wheat cropping in regions of deficient winter rainfall. It has been shown in the diagram relating to each separate season that at flowering time the bulk of the remaining available moisture was supplied from within the 36-48 in. soil zone. As only the heavy summer rainfall can penetrate to this depth, the conservation of this moisture by providing receptive conditions and preventing weed growth during fallow is absolutely essential.

The study of water use by wheat is being continued at Biloela Regional Experiment Station and some aspects will be studied in greater detail. In the summary of findings to date, allowance has not been made for evaporation of moisture from the soil while the crop is growing, and consequently the relationship of temperature, humidity and wind to water use and plant transpiration has not been established. The study of water use and crop yields indicates striking efficiency in production of grain when compared with results reported from other countries (e.g., Cole 1938, Mathews and Brown 1938, Thysell 1938). However, the work at Biloela has only recorded changes in moisture status to a depth of 48 in., and from the data obtained it seems obvious that in the later stages of plant development the root system of wheat in order to obtain all available moisture may penetrate below 48 in.

It is also clear that wheat will utilise water from lower depths when no moisture is present in the surface layers, and in some years an extensive surface rooting system on mature plants may not be present. Hence, in the late growing period one light fall may stimulate a crown rooting system, which could then make use of subsequent rainfall which may only be sufficient to wet the top few inches of soil.

In future, soil moisture observations will be made to lower depths in an endeavour to ascertain with even greater accuracy the ratio of water use to actual grain production. If the use of water below 48 in. totalled 1 in. in the 1948, 1949 and 1951 seasons, the ratio of yield to water use would approximate 5 bus. of grain to 1 in. of water under experimental conditions at Biloela.

As the precipitation during the growing period for wheat at Biloela is frequently inadequate to produce a crop, reliance must be placed on the efficiency of fallowing techniques to conserve up to six inches of available water in the soil before planting. A planting rain of between one and two inches will then assure a grain crop. To obtain a sufficient reserve of moisture the soil surface must be in a receptive condition for rain during the wet summer months. Furthermore, the surface must be maintained in a friable weed-free condition.

The condition of the surface soil and its ability to take in rainfall will be largely influenced by the cropping and farming methods employed. It is considered that in the majority of cases a wheat crop will utilise the current season's rainfall in addition to almost all the available moisture that can be conserved in four or five feet of soil. Only after a succession of years of exceptionally good rainfall or on areas farmed with a high degree of skill will it be possible to conserve more subsoil moisture than can be exhausted by one wheat crop.

Rotational cropping would allow some variation in the utilisation of water from different depths, and similarly the alternation of summer and winter cropping would be advantageous.

V. OTHER FACTORS AFFECTING CROP PRODUCTION.

(1) Soil Nitrogen.

An aspect of crop production which has not been discussed and which is closely related to soil moisture supply is the availability and utilisation of nitrate nitrogen in the soil.

The amount of nitrogen available to growing crops has been studied during many seasons, and the results have indicated considerable variations from year to year. The effects of seasonal conditions and the influences of tillage operations and previous crop history are of paramount importance. It has been shown (Wells 1937) that in the Callide Valley the build-up of nitrate

nitrogen under a cotton crop on old cultivations is particularly rapid, and that this is undesirable for the production of good cotton yields and economic water usage by the plant.

For wheat production, however, an ample supply of available nitrogen is desirable and to obtain the best grain for flour manufacture a high nitrogen supply is essential.

The land on which the crop was sown in 1948 had grown wheat in 1946 and was not planted again until October 1947, when cowpea was sown as a short-term green manure. This crop was ploughed in and the land prepared for wheat.

The nitrate levels in the soil to a depth of 36 in. were good and in the absence of heavy leaching rains and prolific plant growth remained at a favourable level throughout the early growing period. The results of nitrate determinations are shown in Table 13.

Table 13.

NITRATE DETERMINATIONS.

Date of Sampling.	Nitrate N (ppm).			
	Depth of Sample.			
	6″	12″	24″	36″
1–7–48	8·4	4·5	2·2	2·2
19–7–48	7·6	6·2	3·0	2·5
3–8–48	7·0	4·2	2·4	2·3
16–8–48	6·6	2·9	2·1	2·4
30–8–48	4·4	2·3	0·5	1·1
14–9–48	3·3	0·5	0·5	0·5
30–9–48	3·9	0·5	0·5	0·5

The 1948 wheat crop was sown on June 30 and a good germination resulted. There was an initial drop in nitrate nitrogen and slight leaching following 1·40 in. of rain before a more gradual utilisation of nitrate from the upper soil. As this was a very dry growing period, the absence of surface roots may have resulted in less nitrate being used than normally. As active growth occurred, the use of nitrate from the 12 in. level was very marked by the end of four weeks, and the supply had been almost exhausted from the 24 in. and 36 in. zones at the end of eight weeks. No indications of nitrogen deficiency were observed, but only very limited amounts of soil nitrate were present after the flowering period. It was considered possible that nitrate production occurred during the later stages of plant growth.

In 1949 the wheat crop was sown on land which had grown two crops of sorghum after four years of Rhodes grass. The nitrate content of the surface 12 in. was satisfactory. However, in some crops in the district nitrogen deficiency was observed in June and July. It was considered that flood rains during March had leached out the nitrate-nitrogen to some degree and that a heavy weed growth also diminished the available supply before ploughing could commence. Symptoms of deficiency were more obvious in those areas where only a short period elapsed between ploughing and planting of the wheat crop. The 1949 crop produced 37·5 bus. of grain per acre when effective rain during the growing period totalled approximately 1·20 in. Conserved moisture was adequate to mature the crop and nitrate reserves were also satisfactory. Nitrate determinations were made on soil samples from 6 in. and 12 in. depths during the growing period, and although some nitrate was available in the top 12 in. of soil at flowering time, the crop would have exhausted the supply at the lower depths. In the absence of surface moisture and crown rooting the plants were unable to utilise all of the available nitrogen from the top 12 in. of soil.

This point was supported by observations in 1951, when the nitrate content of the upper soil was compared in plots irrigated at flowering time and in plots which did not receive additional water. Samples taken from the irrigated plots indicated 1·6 ppm of nitrate, while the dry plots contained 6·1 ppm in the top 6 in. soil layer. The application of 2 in. of irrigation water at flowering time stimulated root activity and subsequent utilisation of water and nitrate, and increased the yield of grain by 6-12 bus. per acre for different varieties. The nitrate in the unwatered plots was not being utilised by the crop owing to absence of a surface rooting system.

(2) Frosts.

Frost damage which prevents head formation or results in damaged heads and pinched grain is of importance in the Callide Valley wheat areas. Severe frosts in the early stages of growth, which would cause tipping, are not common. Climatic records have been kept at Biloela Regional Experiment Station since 1926 and a study of the incidence of frost has allowed evaluation of planting dates so that the wheat crop will not be in the critical flowering stages during the periods when frosts are of frequent occurrence.

The mean number of frosts (30·4°F. or lower) per month for the last 25 years is as follows:—

Month.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Total for year.
Days per month	0·2	1·7	6·2	10·0	7·1	1·4	0·1	27·3

It will be observed that the occurrence of frost is most frequent in July and August; the latter month is of considerable importance in wheat grain production. A severe frost when heads are being exserted and when flowering has started will cause damage to pollen or small grain. Abortion will also occur to some extent. With a more advanced crop the grain may be checked in formation and a yield of inferior quality will result.

Very low temperatures are recorded in late July and early August and crops sown in May are particularly susceptible at this time.

To overcome the risk of frost damage, planting should be so arranged or varieties so selected that flowering does not occur at the critical period. In practice, using fairly early maturing wheat, plantings during the second week in June have been most successful. In 1930, wheat sown on May 26 was severely damaged by frosts on Aug. 11 and 15, resulting in many sterile heads, and since then it has become a fairly general practice to plant early-maturing varieties for grain production no earlier than the first week of June. With hay wheat these precautions are not necessary.

(3) Varieties for Grain and Hay Production.

During the past 25 years wheat varieties have been grown at Biloela Regional Experiment Station for observation on yield, time of maturity, resistance to drought, and diseases. A certain amount of breeding and selection of strains has been undertaken from time to time.

In the earlier years greater attention was given to hay or dual-purpose types, such as Florence, Warchief and Warren. The low net return for grain wheat did not attract attention nor allow scope for long-term fallowing, and in most years following late summer ploughing there was only sufficient moisture available to permit a hay crop of approximately 100 days' duration to be grown. If sufficient rain was received during the growing period the crop could be stripped for grain, and in favourable years yields ranging from 22 bus. to 30 bus. per acre were recorded.

Effective fallowing and control of weeds after summer rains were somewhat limited in these years by shortage of suitable agricultural machinery. The present equipment permits more efficient and rapid methods and the overall cost of land preparation is proportionately reduced.

By 1930 over a hundred varieties and strains were under observation and it was usual to classify wheats maturing in 132 to 136 days as early types. The plant breeder has been able to reduce this period to 120 days in some present-day varieties without a grave reduction in yield of grain.

In the mid-thirties Florence was still popular, with Warchief, Warren and Clarendon also being widely used for hay. Clarendon and Florence were also satisfactory for grain, and varieties such as Seafoam, Cedric, Flora, Pusa, Seaspray and Three Seas were being sown in increasing amounts. By 1940 Warput was a popular hay type for the Callide Valley, and work was done with many grain varieties in studying resistance to rust. In recent years the varieties under observation for yield and growth studies have been Charter, Seafoam, Gabo, Pusa 4, Puora, Flora, Fedweb 5, Warput, Puglu, a longer term variety Kendee, and many selected strains supplied by wheat breeders.

VI. TIME OF SOWING AND SELECTION OF VARIETIES.

(1) Grain Crops.

The planting rains should be adequate to link up with the underlying wet soil. It has been shown that planting rains exceeding 1·5 in. are more reliable in the late May and June periods (see Tables 8 and 10) and for any degree of success the available moisture must be equivalent to 5 in. of water, as indicated by wet soil present to a depth of at least 40 in. To assure high yields, wet soil should be present from near surface level to slightly over 48 in. in an average Callide Valley alluvial soil.

Observations have shown that early planting, even though limited by planting rains, is unsatisfactory in relation to water use by the crop. When mid-season or early-maturing varieties are planted very early in March or April in order to obtain use of the June rains during the growing period, they do not gain any advantage, owing to the longer growth period imposed upon the crop by early planting. Mid-season varieties sown in April require 160 days to reach maturity, while the same varieties sown in early June reach maturity in 140 days.

The longer life span is not desirable as it necessitates the availability of water over a longer period and the moisture factor is so critical at the termination of the growing period that utilisation over an additional 10-20 days may result in a significant reduction in crop prospects. In addition to this, earlier planting increases the risk of frost damage by bringing the flowering stage into July or early August, when frost incidence is at a maximum.

Thus to encourage earliness of maturity and consequent efficient use of the limited available moisture, the later plantings which also coincide with better prospects of planting rains are generally recommended.

It has also been shown that very late plantings are to be avoided, as establishment rains in the late July-August period are most unreliable. The crop should be matured and harvested before the onset of storms in November; hence a late May or early June planting is desirable to avoid this risk.

When all factors are considered it becomes clear that a fairly early maturing variety sown in the mid-planting season appears most desirable. Varieties with this essential characteristic are under test for yield and resistance to disease at the Biloela Station.

It should be noted that in years of highly favourable conditions the long-term varieties may outyield the short-season types, but the degree of risk involved in the Callide Valley is high and crop failures would be common.

In most years some moisture stress is evident between the flowering and maturity stages and it is during this critical period that rain can be of considerable value in the production of a good grain crop. It is believed that the stimulation of crown rooting and subsequent utilisation of even small rainfalls which moisten the top few inches of soil are essential requirements for very high yields. Normally some forcing of maturity is noted as available soil moisture is exhausted, and only the short-season varieties can reach full heading before moisture deficiency becomes obvious. Sufficient water can be stored in these soils to produce a good grain crop—say 30 bus. per acre—but in years where only limited conservation has been possible further rain at flowering time is essential to obtain such yields.

From 1948, 20 selected varieties have been tested for Callide Valley conditions and six of these have been grown in seven consecutive years. Comparable yield data are shown in Table 14. The yield figures do not indicate significant differences by statistical analyses but a definite trend is shown in favour of Gabo and Pusa 4 over the 7-year period.

Table 14.

Yield of Six Leading Wheat Varieties, Biloela Regional Experiment Station, 1948–1954.

Year.	Germination.	Gabo.	Pusa 4.	Puno.	Charter.	Puora.	Seafoam.
		bus./ac.	bus./ac.	bus./ac.	bus./ac.	bus./ac.	bus./ac.
1948	30–6–48	37·4	38·8	42·1	39·7	38·1	34·2
1949	6–6–49	39·7	34·3	37·5	31·9	33·0	33·4
1950	2–6–50	40·0	41·2	34·2	35·1	34·8	31·8
1951	6–7–51	30·3	31·7	27·5	29·8	28·9	26·5
1952	3–6–52	36·6	25·1	24·9	26·5	26·2	32·4
1953*	2–9–53	23·1	18·8	24·3	24·4	16·6	15·8
1954	9–6–54	36·2	40·5	38·3	39·6	40·6	42·3
Mean of 7 years		34·8	32·9	32·7	32·4	31·2	30·9

* Extremely dry winter and very late plantings.

Kendee has given good yields when sown early under favourable conditions and with sufficient moisture to maintain the crop over a longer growth period, and the early variety Spica has given very favourable results over the last three years. Saga and Festival have also been grown, the former yielding over 40 bus. per acre in 1954.

In assessing the potential value of varieties, factors such as resistance to rust and other diseases, straw strength and the quality of grain must be evaluated. Spica lodged badly in 1952 and Festival lodged more than any other variety in 1954. Pusa 4, Puora and Puno are susceptible to rust. Gabo is rather deceptive and often exceeds a visual estimate of yield. The grain of KGPF 4521, a high-yielding variety, was unsuitable for milling. A number of selections and strains are giving favourable results and work in collaboration with the wheat breeders will continue.

(2) Hay Crops.

The availability of green fodder for grazing in the winter months is most desirable in the dairying districts and hay may be conserved for general or drought feeding. Quite different circumstances are required to produce a crop primarily suitable for haymaking, although in practice many crops grown for grain are utilised for hay or grazing when it is obvious that the grain yield will be very poor.

Hay crops may be harvested 90-110 days after germination and the time factor as related to water use is less critical than for grain production. As the grain has not to be matured, long-season or mid-season varieties can be grown to produce satisfactory bulk. Very early plantings in March or April are not recommended, since observations in the Callide Valley have shown that planting and establishment rains are not favourable and high water usage in the April-May period may result in crop failure through moisture deficiency. In some years high yields of hay were obtained by early planting, but in these cases heavy rains were recorded in April or May. (One year Florence was sown on Mar. 1 and due to good rains in April a hay cut of 2½ tons per acre was obtained on May 22, 83 days afterwards).

For grain production it is a disadvantage to produce lush vegetative growth in the early stages, as the maintenance of such a stand through to maturity demands far more water than can be stored in the soil, and rains must be received to produce a crop. However, such years are favourable for hay production and with mid-season or long-term varieties there is a good chance of carrying a crop which commenced under luxury conditions for 90-100 days on stored moisture to obtain a satisfactory harvest. Short-season varieties, though more economical in regard to water use, normally fail to produce the bulk of green material on good stout stems so necessary for hay production. It is true that plantings for hay should be made somewhat earlier than when grain varieties are used and that longer term varieties should be sown. If early growth is good or the crop shows signs of going to head too early, a light grazing may be beneficial, but in the Callide Valley in most seasons the nitrogen level may be inadequate to produce a heavy crop after the first flush has been grazed off.

The long-season varieties may be sown from early May and the mid-season types from the middle to the end of May. To avoid risk of frost damage in late July and August, if the crop is carried through for grain, dual-purpose crops should not be planted before the end of May.

Testing of present varieties of hay or grazing wheats has been rather limited at the Biloela Station. However, the most suitable available varieties are Lawrence and Celebration, and a selection from Currawa (CHFCur) is showing very promising results.

REFERENCES.

Cole, J. S. 1938. Correlations between annual precipitation and the yield of spring wheat in the Great Plains. Tech.Bull.U.S.Dep.Agric. 636.

Mathews, O. R., and Brown, L. A. 1938. Winter wheat and sorghum production in the southern Great Plains under limited rainfall. Circ.U.S.Dep.Agric. 477.

Thysell, J. C. 1938. Conservation and the use of soil moisture at Mandan, N.Dak. Tech.Bull.U.S.Dep.Agric. 617.

Wells, W. G. 1937. Cotton growing in Queensland. J.Aust.Inst.Agric.Sci. 3:147-153.

NODULATION OF LEGUMES INDIGENOUS TO QUEENSLAND

By G. D. BOWEN, B.Sc., Assistant Pathologist, Division of Plant Industry.

SUMMARY.

Information available on nodulation and cross-infection of Queensland indigenous legumes is assembled.

Nodulation is recorded on 29 previously unlisted indigenous species, including 2 unlisted genera.

The ability of isolates from 13 species to infect cowpea (Vigna sinensis **(L.) Endl. ex Hassk.) is recorded.**

The information on nodulation and cross-infection for indigenous legumes in the whole of Australia is assembled as an appendix.

I. NODULATION.

Allen and Allen (1954) reported that only about 1,200 of the estimated 10,000 species in the family *Leguminosae* have been examined for the presence or absence of root nodules due to infection by species of the bacterial genus *Rhizobium* Frank.

Bailey (1913) recorded 458 indigenous Queensland leguminous species in 84 genera. Species and recognised varieties (to some of which species rank is now attributed) numbered 553. Since this work 24 species have been added and the number of recognised genera raised to 90.

The presence of nodules on 83 of the indigenous species in 36 genera has been recorded in various papers by Australian and overseas workers. The species are listed together with available data on cross-infection in Table 1.

Table 1.

Recorded Nodulation of Queensland Indigenous Legumes.

Host.	Authority for Record of Nodulation.	Recorded Behaviour with Respect to Cross-inoculation Groups.*†	Authority for Cross-inoculation Data.
PAPILIONOIDEAE.			
Tribe Podalyrieae			
Aotus lanigera A. Cunn. ex Benth. ..	21,*		
Daviesia corymbosa Sm...	19		
D. ulicifolia Andr. (*D. ulicina* Sm.) ..	19,*		
Dillwynia ericifolia Sm...	18		
D. floribunda Sm.	18, 19,*		
Jacksonia scoparia R. Br.	21,*	C	21
Mirbelia reticulata Sm.	21,*	C	21
Pultenaea daphnoides Wendl.	18, 19		
P. myrtoides A. Cunn. ex Benth. ..	21	C	21
P. villosa Willd.	21,*	C	21,*
Viminaria juncea (Schrad.) Hoffmgg. (*V. denudata* Sm.)	18		
Tribe Genisteae			
Bossiaea prostrata R. Br.	19		
Crotalaria cunninghamii R. Br. ..	1	C	1
C. incana L.	1, 6, 11, 28, 30, 33, 34	C (C)	1, 11, 30, 33
C. juncea L.	6, 9, 11, 16, 25, 27, 30, 33	C (C, P, Lo, M, T)	9, 11, 16, 25, 27, 30, 33
C. quinquefolia L.	6		
C. laburnifolia L.	28		
C. mucronata Desv. (*C. striata* DC.) ..	9, 11, 28, 30, 34,	C (C)	9, 11, 30
C. retusa L.	11, 16, 30, 33	C (C)	11, 16, 30, 33
C. verrucosa L.	11, 28, 30, 31, 33,	C (C)	11, 30, 31, 33
Goodia lotifolia Salisb. (*G. medicaginea* F. Muell.)	19		
Platylobium formosum Sm.	21,*	C	21
Tribe Trifolieae			
Trigonella suavissima Lindl.	29		
Tribe Euloteae			
Lotus australis Andr.	19		
Tribe Galegeae			
Indigofera australis Willd.	19,*		
I. hirsuta L.	1, 6, 9, 28,*	C	1, 9
I. trita L.f.	30	(C, P, B, T)	30
I. viscosa Lam.	30, 32, 33	C (C, Lu)	30, 32, 33
Psoralea patens Lindl.	19		
Tephrosia purpurea (L.) Pers.	2, 6, 25	C	2, 25
Sesbania bispinosa (Jacq.) Fawcett & Rendle (*S. aculeata* (Willd.) Pers.)	20, 25,*	Strain specific—affinities to B, Lu, and C	20, 25

Table 1—continued.

Host.	Authority for Record of Nodulation.	Recorded Behaviour with Respect to Cross-inoculation Groups.*†	Authority for Cross-inoculation Data.
PAPILIONOIDEAE.—*Continued.*			
S. grandiflora (L.) Pers...	6, 20	Strain specific—affinities to B and C	20
Swainsona galegifolia (Andr.) R. Br. (*S. coronillifolia* Salisb.)	30,*	(C, Lu, P)	30
Tribe Hedysareae			
Aeschynomene americana L.	11, 23	C	11
A. indica L.	4, 6,*		
Alysicarpus rugosus (Willd.) DC. ..	1, 28	C	1
A. vaginalis (L.) DC. (*A. nummularifolius* (L.) DC.)	1, 2, 6, 28, 33, 34	C	1, 2, 33
Desmodium gangeticum (L.) DC. ..	6		
D. polycarpon (Poir.) DC. (—*um*) ..	30	(C, T, B)	30
Lespedeza sericea (Thunb.) Miq. (*L. cuneata* (D. Don) G. Don)	2, 3, 11, 13, 16, 27	C	2, 3, 11, 13, 16, 27
Phyllodium pulchellum Desv. (*Desmodium pulchellum* (Desv.) Benth.)	6		
Uraria lagopodioides (L.) D. Don. (*lagopoides*)	6		
Tribe Phaseoleae			
Abrus precatorius L.	1, 6	C	1
Dolichos biflorus L.	16, 24, 25, 28	C, Lu	16, 24, 25
Erythrina indica Lam.	1, 2, 9	C	1, 2, 9
Hardenbergia violacea (Schneev.) Stearn (*H. monophylla* (Vent.) Benth., *Kennedya monophylla* Vent.)	19, 30,*	C (C, Lo, Lu, P, M, T, B)	30,*
Kennedya prostrata R. Br.	19		
Mucuna gigantea (Willd.) DC.	1	C	1
Phaseolus mungo L.	12, 16, 25	C, Lu.	16, 25
Rhynchosia minima (L.) DC.	28, 32, 33,*	C	32, 33
Vigna marina (Burm.) Merr. (*V. retusa* Walp.)	1, 2, 30	C (C, Lu, P, B, T)	1, 2, 30
V. vexillata (L.) Benth.	28, 30	(C, P,B,T)	30
CAESALPINIOIDEAE			
Tribe Cassieae			
Cassia mimosoides L.	1, 2, 6	C	1, 2
MIMOSOIDEAE.			
Tribe Acacieae			
Acacia acinacea Lindl.	19		
A. anceps DC.	19		
A. arabica (Lam.) Willd.	1	C	1
A. armata R. Br.	16, 19	C	16

Table 1—continued.

Host.	Authority for Record of Nodulation.	Recorded Behaviour with Respect to Cross-inoculation Groups.*†	Authority for Cross-inoculation Data.
MIMOSOIDEAE.—*Continued.*			
A. auriculiformis A. Cunn. ex Benth...	1	C	1
A. baileyana F. Muell.	1, 33	C	1, 33
A. cultriformis A. Cunn. ex G. Don ..	33	C	33
A. cunninghamii Hook.	21,*	C	21,*
A. dealbata (Page) Link.	33	C	33
A. decurrens (Wendl.) Willd.	1, 30	C (C, P, Lo)	1, 30
A. discolor (Lam.) Willd.	18		
A. elata A. Cunn. ex Benth.	18		
A. farnesiana (L.) Willd.	1, 6,*	C	1
A. floribunda (Vent.) Willd.	16, 33	C	16, 33
A. granitica Maid.	21	C	21
A. juniperina (Vent.) Willd.	18,*		
A. latifolia Benth.	33	C	33
A. ligulata A. Cunn. ex Benth. ..	19		
A. linifolia (Vent.) Willd.	16, 18	C	16
A. longifolia (Andr.) Willd.	16	C	16
A. melanoxylon R. Br.	16, 33	C	16, 33
A. myrtifolia (Sm.) Willd.	19		
A. obliqua A. Cunn. ex Benth. ..	28		
A. podalyriifolia A. Cunn. ex G. Don	21,*	C	21
A. pycnantha Benth.	19		
A. retinodes Schlecht.	19		
A. salicina Lindl.	19		
A. sophorae (Labill.) R. Br.	19		
A. spinescens Benth.	19		
Tribe Ingeae			
Albizia procera (Roxb.) Benth. ..	1	C	1

* Indicates results obtained by the author.

† The symbols in column 3 refer to the following cross-inoculation groups :—

B Garden bean
C Cowpea (including soybean)
Lo Lotus
Lu Lupin
M Medic
P Garden pea
T Trifolium

Where brackets are used in column 3 the cross-infection data within the brackets are derived from the work of J. K. Wilson (1939a), whose cross-inoculation data frequently do not concur with those of other authorities.

During current investigations on legume nodulation in Queensland many native legumes have been examined. The presence of nodules on 29 species on which nodules apparently had not been recorded previously has been noted as shown in Table 2.

Table 2.

New Recordings for Nodulation.

PAPILIONOIDEAE.

Tribe Podalyrieae

Aotus villosa (Andr.) Sm.
Chorizema parviflorum Benth.
Daviesia umbellulata Sm.
Dillwynia peduncularis Benth.
Gompholobium pinnatum Sm.
G. virgatum Sieb. ex DC.
Phyllota phylicoides (Sieb. ex DC.) Benth.
Pultenaea microphylla Sieb. ex DC.
P. ?retusa Sm.

Tribe Genisteae

Crotalaria linifolia L.f.
Hovea acutifolia A. Cunn. ex G. Don

Tribe Galegeae

Indigofera enneaphylla L.
Psoralea tenax Lindl.

Tribe Hedysareae

Desmodium nemorosum F. Muell. ex Benth.
D. muelleri Benth.
D. rhytidophyllum F. Muell. ex Benth.
D. varians (Labill.) G. Don
Dicerma biarticulatum (L.) DC.
Zornia diphylla (L.) Pers.

Tribe Phaseoleae

Clitoria australis Benth.
Glycine clandestina Wendl.
G. tabacina (Labill.) Benth.
G. tomentosa (Benth.) Benth.
Vigna lanceolata Benth.

MIMOSOIDEAE

Tribe Adenanthereae

Neptunia gracilis Benth.

Tribe Acacieae

Acacia falcata Willd.
A. fimbriata A. Cunn. ex G. Don
A. pubescens (Vent.) R. Br.
A. suaveolens (Sm.) Willd.

The foregoing data, together with all available records on nodulation of legumes indigenous to the other Australian States, are summarized in an appendix.

The 90 genera of *Leguminosae* with members indigenous to Queensland are distributed as follows :—72 in *Papilionoideae*, 11 in *Caesalpinioideae*, and 7 in *Mimosoideae*. The distribution within these sub-families of Queensland genera with indigenous species for which nodulation has been recorded is now 41, 1, and 3 respectively. Of the remaining 31 Queensland genera of the *Papilionoideae*, 9 possess nodulating species not indigenous to Queensland, while for 22 there is no record of observation. If non-indigenous species are considered, no members of 10 of the 11 genera of *Caesalpinioideae* present in Queensland have been recorded to nodulate. This is due partly to lack of observations, although Allen and Allen (1947) recorded a relative lack of nodulation in this sub-family. Records of nodulation of non-indigenous legumes occur in 2 of the 4 genera of *Mimosoideae* lacking nodulation recordings in Queensland.

No previous reference to nodulation of members of the genera *Dicerma* DC., and *Zornia* Gmel. has been found.

A list of the introduced legumes of the cowpea miscellany nodulating naturally in various parts of Queensland is given in Table 3.

Table 3.

Introduced Legumes of the Cowpea Miscellany Nodulating Naturally in Queensland.

Arachis hypogea L.
Cajanus cajan (L.) Millsp.
Calopogonium mucunoides Desv.
Centrosema pubescens Benth.
Clitoria ternatea L.
Crotalaria goreensis Guill. & Perr.
C. usaramoensis Bak. f.
Desmodium canum (J. F. Gmel.) Schinz & Thell.
D. heterophyllum (Willd.) DC.
D. ovalifolium Wall. ex Merr.
D. scorpiurus (Sw.) Desv.
D. tortuosum (Sw.) DC.
D. triflorum (L.) DC.
D. uncinatum (Jacq.) DC.
Dolichos lablab L.
Glycine javanica L.
G. max (L.) Merr.
Mimosa pudica L.
Phaseolus lathyroides L.

Pueraria phaseoloides (Roxb.) Benth.
P. thunbergiana (S. & Z.) Benth.
Stylosanthes gracilis H.B.K.
S. sundaica Taub.
Tephrosia candida (Roxb.) DC.
Vigna sinensis (L.) Endl. ex Hassk.

II. CROSS-INFECTION.

The cross-infection data in Table 1 have been summarized and generalised on the basis of the cross-inoculation group distinctions used by Fred, Baldwin and McCoy (1932). Wilson (1939) has criticised the cross-inoculation group concept. Cross-inoculation data of Johnson and Allen (1952) and Raju (1936) indicate definite links between the cowpea " cross-inoculation " group and each of the bean group, the lupin group and the strain-specific Sesbania series.

A study of information on the cowpea and soybean cross-inoculation groups leaves little justification for the retention of a distinction between these two, any differences in infectivity being of no higher order than that of specificity recorded for other members of the cowpea miscellany. In Tables 1 and 4 (in appendix), plants listed in the cowpea miscellany have been so placed on the basis of infection studies with *Vigna sinensis* or with other members recognised in this group. The soybean and cowpea groups have been merged in these tables.

Preliminary work in this laboratory has indicated that isolates from several species of Queensland indigenous legumes have the ability to infect *V. sinensis*. These include isolates from :—

Acacia cunninghamii Hook.
A. fimbriata A. Cunn. ex G. Don
A. juniperina (Vent.) Willd.
Chorizema parviflorum Benth.
Desmodium rhytidophyllum F. Muell. ex Benth.
D. varians (Labill.) G. Don
Dillwynia floribunda Sm.
Glycine clandestina Wendl.
Gompholobium virgatum Sieb. ex DC.
Hardenbergia violacea (Schneev.) Stearn
Hovea acutifolia A. Cunn. ex G. Don
Pultenaea microphylla Sieb. ex DC.
P. villosa Willd.

Pultenaea villosa and *Acacia cunninghamii* have previously been recorded to infect cowpea (McKnight 1949), as has *Hardenbergia violacea* (Wilson 1939 a).

With the exception of *Sesbania bispinosa* (*S. aculeata*) *and S. grandiflora*, all Queensland species studied for cross-infection belong to the cowpea miscellany.

There is no published information on *Trigonella suavissima* or *Lotus australis*. The genus *Trigonella* is placed in the medic cross-inoculation group and the genus *Lotus* in the Lotus cross-inoculation group (Fred, Baldwin and McCoy 1932).

III. DISTRIBUTION.

Over wide areas of Queensland from latitude 28°S to latitude 17°S, particularly in the coastal belt, cultivated tropical legumes (Table 3) planted without inoculation have been observed. Nodulation is frequently present and invariably occurs in well-established stands.

Intensive observations of both native and planted tropical legumes in the coastal areas between latitude 17°S and latitude 19°S have given no indication of a sparsity of nodulation in the tropics, as is sometimes suggested. The results of Bañados and Fernandez (1954) confirm the presence of the nodulation phenomenon in similar latitudes in the northern hemisphere.

The widespread occurrence of cowpea-type legumes in Queensland makes it almost inevitable that legume bacteria of the cowpea miscellany are widely distributed. This has in fact been found. Nevertheless, responses of the tropical legumes to inoculation have often been obtained. Experimental work in this laboratory indicates that the response of such legumes to inoculation is influenced by host specificity within the cowpea miscellany, localised field distribution of organisms effective on the particular host, and relative effectiveness of different organisms on a host.

IV. ACKNOWLEDGEMENT.

The author wishes to express his thanks to Mr. S. T. Blake, Botanist, Department of Agriculture and Stock, for identifying plants and providing information on their nomenclature and distribution.

REFERENCES.

1. Allen, O. N., and Allen, E. K. 1936. Root nodule bacteria of some tropical leguminous plants : I. Cross-inoculation studies with *Vigna sinensis* L. Soil Sci. 42 : 61–77.

2. Allen, O. N., and Allen, E. K. 1939. Root nodule bacteria of some tropical leguminous plants : II. Cross-inoculation tests within the cowpea group. Soil Sci. 47 : 63–76.

3. Allen, O. N., and Allen, E. K. 1954. Morphogenesis of the leguminous root nodule. *In* Abnormal and Pathological Plant Growth. Brookhaven Symposia in Biol. 6 : 209–34.

4. Arora, N. 1954. Morphological development of the root and stem nodules of *Aeschynomene indica* L. Phytomorph. 4 : 211–16.

5. Bailey, F. M. 1913. Comprehensive Catalogue of Queensland Plants. Government Printer : Brisbane.

6. Banados, L. L., and Fernandez, W. L. 1954. Nodulation among the Leguminosae. Philipp.Agric. 37 : 529–33.

7. Bentham, G. 1864. Flora Australiensis. Vol. 2. Lovell Reeve & Co. : London.

8. Black, J. M. 1948. Flora of South Australia, 2nd ed., Part 2. Government Printer : Adelaide.

9. Burton, J. C. 1952. Host specificity among certain plants in the cowpea cross-inoculation group. Proc.Soil Sci.Soc.Amer. 16 : 356–8.

10. Bushnell, O. A., and Sarles, W. B. 1937. Studies on the root-nodule bacteria of wild leguminous plants in Wisconsin. Soil Sci. 44 : 409–23.

11. Carroll, W. R. 1934. A study of Rhizobium species in relation to nodule formation on the roots of Florida legumes : I. Soil Sci. 37 : 117–35.

12. Duggar, J. F. 1935. The nodulation and other adaptations of certain summer legumes. J.Amer.Soc.Agron. 27 : 32–7.

13. Erdman, L. W. 1951. The effectivity of different strains of *Rhizobium* on annual and perennial lespedezas. Proc. Soil Sci.Soc.Amer. 15 : 173–6.

14. Ewart, A. J. 1930. The Flora of Victoria. Government Printer : Melbourne.

15. Ewart, A. J., and Davies, O. B. 1917. The Flora of the Northern Territory. Dept. of Home and Territories : Melbourne.

16. Fred, E. B., Baldwin, I. L., and McCoy, Elizabeth. 1932. Root nodule bacteria and leguminous plants. Univ.Wis.Stud.Sci. 5.

17. Gardner, C. A. 1930. Enumeratio Plantarum Australis Occidentalis. Government Printer: Perth.

18. Hannon, N. J. 1949. The nitrogen economy of the Hawkesbury sandstone soils around Sydney. The role of the native legumes. Honours Thesis, University of Sydney.

19. Harris, J. R. 1953. List of species of bacterial genus *Rhizobium* maintained in the type collection of C.S.I.R.O. Division of Soils, Adelaide. Commonw.Sci.Industr.Res.Org. Div.Soils Memo. 10/53.

20. Johnson, M. D., and Allen, O. N. 1952. Nodulation studies with special reference to strains isolated from *Sesbania* species. Leeuwenhoek Ned. Tijdschr. 18 : 13–22.

21. McKnight, T. 1949. Efficiency of isolates of *Rhizobium* in the cowpea group, with proposed additions to the group. Qd J.Agric.Sci. 6 : 61–76.

22. Maiden, J. M., and Betche, E. 1916. A Census of New South Wales Plants. Government Printer : Sydney.

23. Martin, W. P. (with the co-operation of others). 1948. Observations on the nodulation of leguminous plants of the south-west. U.S.Dep.Agric.Soil Cons.Serv.Reg. 6 Reg. Bull.107.

24. Palacios, G., and Bari, A. 1936. The physiology of Indian nodule bacteria. Proc.Indian Acad.Sci. 3 : 334–60.

25. Raju, M. S. 1936. Studies on the bacterial-plant groups of cowpea, cicer and dhaincha. I. Classification. Zbl. Bakt. 94 : 249–62.

26. Rodway, L. 1903. The Tasmanian Flora. Government Printer : Hobart.

27. University of Pretoria. 1954. Studies on the symbiotic nitrogen fixation in legumes of importance to southern Africa. Rpt. on Nuffield Foundation Grant, Pl.Phys.Res. Inst. Univ.Pretoria, May, 1954.

28. University of Pretoria. 1955. Studies on the symbiotic nitrogen fixation of legumes of importance to southern Africa. Rpt. on Nuffield Foundation Grant, Pl.Phys.Res. Inst. Univ.Pretoria, May, 1955.

29. Vincent, J. M. 1955. Personal communication.

30. Wilson, J. K. 1939a. Leguminous plants and their associated organisms. Cornell Agric.Exp.Sta. Mem. 221.

31. Wilson, J. K. 1939b. A relation between pollination and nodulation of the *Leguminoseae*. J.Amer.Soc.Agron. 31 : 159–70.

32. Wilson, J. K. 1939c. Symbiotic promiscuity of two species of Crotalaria. J.Amer.Soc. Agron. 31 : 934–9.

33. Wilson, J. K. 1945. The symbiotic performance of isolates from soybean with species of Crotalaria and certain other plants. Cornell Agric.Exp.Sta. Mem. 267.

34. Wilson, J. K. 1948. Symbiotic segregation of strains of the root nodule bacteria by leguminous plants. Cornell Agric.Exp.Sta.Mem. 279.

APPENDIX.

Nodulation of Australian Indigenous Legumes.

In the course of compiling the foregoing paper data were collected on the Australian indigenous legume flora with respect to nodulation and cross-infection. These are presented in Table 4 together with the data appearing in the previous tables.

Authorities consulted with respect to the indigenous nature of the plants were the relevant floras of each State (Bailey 1913, pp. 124–166 ; Black 1948, pp. 399–481 ; Ewart 1930, pp. 573–680 ; Ewart and Davies 1917, pp. 118–154 ; Gardner 1930, pp. 49–66 ; Maiden and Betche 1916, pp. 89–110 ; Rodway 1903, pp. 30–43) and " Flora Australiensis " (Bentham 1864, pp. 1 425). Bentham (1864) recorded 957 species of *Leguminosae* in 91 genera as indigenous. The number known at present would approach 1,100 species in 101 genera.

It is seen that the number of species observed to nodulate now stands at 135 in 48 genera. No record of the presence of nodules has been made with 40 genera indigenous to Australia. Records of nodulation of overseas species of the other 13 genera have been made.

Table 4.

Nodulation Behaviour of Australian Indigenous Legumes.

Host.	Authority for Record of Nodulation.	Recorded Behaviour with Respect to Cross-inoculation Groups.†	Authority for Cross-inoculation Data.
Abrus precatorius L.	1, 6	C	1
Acacia acinacea Lindl.	19		
A. anceps DC.	19		
A. arabica (Lam.) Willd.	1	C	1
A. armata R. Br.	16, 19	C	16
A. auriculiformis A. Cunn. ex Benth...	1	C	1
A. baileyana F. Muell.	1, 33	C	1, 33
A. cultriformis A. Cunn. ex G. Don ..	33	C	33
A. cunninghamii Hook.	21,*	C	21,*
A. dealbata (Page) Link.	33	C	33

* *See* footnote to Table 1.

† *See* footnote to Table 1.

Table 4—continued.

Host.	Authority for Record of Nodulation.	Recorded Behaviour with Respect to Cross-inoculation Groups.†	Authority for Cross-inoculation Data.
A. decurrens (Wendl.) Willd.	1, 30	C (C, P, Lo)	1, 30
A. discolor (Lam.) Willd.	18		
A. elata A. Cunn. ex Benth.	18		
A. falcata Willd.	*		
A. farnesiana (L.) Willd.	1, 6,*	C	1
A. fimbriata A. Cunn. ex G. Don ..	*	C	*
A. floribunda (Vent.) Willd.	16, 33	C	16, 33
A. granitica Maid.	21	C	21
A. juniperina (Vent.) Willd.	18,*	C	*
A. latifolia Benth.	33	C	33
A. ligulata A. Cunn. ex Benth. ..	19		
A. linifolia (Vent.) Willd.	16, 18	C	16
A. longifolia (Andr.) Willd.	16	C	16
A. melanoxylon R. Br.	16, 33	C	16, 33
A. myrtifolia (Sm.) Willd.	19		
A. obliqua A. Cunn. ex Benth. ..	28		
A. podalyriifolia A. Cunn. ex G. Don	21,*	C	21
A. pubescens (Vent.) R. Br.	*		
A. pycnantha Benth.	19		
A. retinodes Schlecht.	19		
A. salicina Lindl.	19		
A. sophorae (Labill.) R. Br.	19		
A. spinescens Benth.	19		
A. suaveolens (Sm.) Willd.	*		
Aeschynomene americana L.	11, 23	C	11
A. indica L.	4, 6,*		
Albizia lophantha (Willd.) Benth. ..	16	C	16
A. procera (Roxb.) Benth.	1	C	1
Alysicarpus longifolius (Rottl.) Wight & Arnott	1, 27, 28	C	1
A. rugosus (Willd.) DC.	1, 28	C	1
A. vaginalis (L.) DC. (*A. nummularifolius* (L.) DC.)	1, 2, 6, 28, 33, 34	C	1, 2, 33
Aotus lanigera A. Cunn. ex Benth. ..	21,*		
A. villosa (Andr.) Sm.	*		
Bossiaea prostrata R. Br.	19		
Cassia mimosoides L.	1, 2, 6	C	1, 2
Chorizema ilicifolium Labill.	30	(C, P, Lo, M, B, T)	30
C. parviflorum Benth.	*	C	*
Clianthus speciosus (G. Don) Aschers. & Graebn. (*C. dampieri* A. Cunn. ex Lindl.)	19, 30	(C, P, Lu, M)	30
Clitoria australis Benth.	*		

* *See* footnote to Table 1.

† *See* footnote to Table 1.

Table 4—continued.

Host.	Authority for Record of Nodulation.	Recorded Behaviour with Respect to Cross-inoculation Groups.†	Authority for Cross-inoculation Data.
Crotalaria cunninghamii R. Br. ..	1	C	1
C. incana L.	1, 6, 11, 28, 30, 33, 34	C, (C)	1, 11, 30, 33
C. juncea L.	6, 9, 11, 16, 25, 27, 30, 33	C, (C, P, Lo, M, T.)	9, 11, 16, 25, 27, 30, 33
C. quinquefolia L.	6		
C. laburnifolia L.	28		
C. linifolia L.f.	*		
C. mucronata Desv. (*C. striata* DC.) ..	9, 11, 28, 30, 34	C, (C)	9, 11, 30
C. retusa L.	11, 16, 30, 33	C, (C)	11, 16, 30. 33
C. verrucosa L.	11, 28, 30, 31, 33	C, (C)	11, 30, 31. 33
Daviesia corymbosa Sm...	19		
D. ulicifolia Andr. (*D. ulicina* Sm.) ..	19,*		
D. umbellulata Sm.	*		
Desmodium gangeticum (L.) DC. ..	6		
D. muelleri Benth.	*		
D. nemorosum F. Muell. ex Benth. ..	*		
D. polycarpon (Poir.) DC. (—*um*) ..	30	(C, T, B)	30
D. rhytidophyllum F. Muell. ex Benth.	*	C	*
D. varians (Labill.) G. Don	*	C	*
Dicerma biarticulatum (L.) DC. (*Desmodium biarticulatum* (L.) F. Muell.)	*		
Dillwynia ericifolia Sm...	18		
D. floribunda Sm.	18, 19,*	C	*
D. hispida Lindl.	19		
D. peduncularis Benth.	*		
Dolichos biflorus L.	16, 24, 25, 28	C, Lu	16, 24, 25
Erythrina indica Lam.	1, 2, 9	C	1, 2, 9
Eutaxia microphylla (R. Br.) J. M. Black	19		
Glycine clandestina Wendl.	*	C	*
G. tabacina (Labill.) Benth.	*		
G. tomentosa (Benth.) Benth.	*		
Gompholobium minus Sm.	19		
G. pinnatum Sm.	*		
G. virgatum Sieb. ex DC.	*	C	*
Goodia lotifolia Salisb. (*G. medicaginea* F. Muell.)	19		
Hardenbergia violacea (Schneev.) Stearn (*H. monophylla* (Vent.) Benth., *Kennedya monophylla* Vent.)	19, 30,*	C. (C, Lo, Lu, P, M, T, B)	30,*
Hovea acutifolia A. Cunn. ex G. Don ..	*	C	*

* *See* footnote to Table 1.

† *See* footnote to Table 1.

Table 4—continued.

Host.	Authority for Record of Nodulation.	Recorded Behaviour with Respect to Cross-inoculation Groups.†	Authority for Cross-inoculation Data.
Indigofera australis Willd.	19,*		
I. enneaphylla L.	*		
I. hirsuta L.	1, 6, 9, 28,*	C	1, 9
I. trita L.f.	30	(C, P, B, T)	30
I. viscosa Lam.	30, 32, 33	C, (C, Lu)	30,32,33
Jacksonia scoparia R. Br.	21,*	C	21
Kennedya prostrata R. Br.	19		
Lespedeza sericea (Thunb.) Miq. (*L. cuneata* (D. Don) G. Don)	2, 3, 11, 13, 16, 27	C	2, 3, 11, 13, 16, 27
Lotus australis Andr.	19		
Mirbelia reticulata Sm.	21,*	C	21
Mucuna gigantea (Willd.) DC.	1	C	1
Neptunia gracilis Benth.	*		
Phaseolus mungo L.	12, 16, 25	C, Lu	16, 25
Phyllodium pulchellum Desv. (*Desmodium pulchellum* (Desv.) Benth.)	6		
Phyllota phylicoides (Sieb. ex DC.) Benth.	*		
P. pleurandroides F. Muell.	19		
Platylobium formosum Sm.	21,*	C	21
P. obtusangulum Hook.	19, 30	(C, Lo)	30
Psoralea patens Lindl.	19		
P. tenax Lindl.	*		
Pultenaea acerosa R. Br. ex Benth. ..	19		
P. canaliculata F. Muell.	19		
P. daphnoides Wendl.	18, 19		
P. densifolia F. Muell.	19		
P. elliptica Sm.	18		
P. involucrata Benth.	19		
P. largiflorens F. Muell. var. *latifolia* H. B. Williamson	19		
P. laxiflora Benth. var. *pilosa* H. B. Williamson	19		
P. microphylla Sieb. ex DC.	*	C	*
P. myrtoides A. Cunn. ex. Benth ..	21	C	21
P. prostrata Benth.	19		
P. ? retusa Sm.	*		
P. scabra R. Br.	19		
P. stipularis Sm.	18		
P. tenuifolia R. Br.	19		

* *See* footnote to Table 1.
† *See* footnote to Table 1.

Table 4—continued.

Host.	Authority for Record of Nodulation.	Recorded Behaviour with Respect to Cross-inoculation Groups.†	Authority for Cross-inoculation Data.
P. teretifolia H. B. Williamson var. *brachyphylla* H. B. Williamson	19		
P. villosa Willd.	21,*	C	21,*
Rhynchosia minima (L.) DC.	28, 32, 33,*	C.	32, 33
Sesbania bispinosa (Jacq.) Fawcett Rendle (*S. aculeata* (Willd.) Pers.)	20, 25,*	Strain specific—affinities to B, Lu, and C	20, 25
S. grandiflora (L.) Pers...	6, 20	Strain specific—affinities to B and C	20
Swainsona galegifolia (Andr.) R. Br. (*S. coronillifolia* Salisb.)	30,*	(C, Lu, P)	30
S. lassertiifolia DC.	19		
Templetonia retusa (Vent.) R. Br. ..	19		
Tephrosia purpurea (L.) Pers.	2, 6, 25	C	2, 25
Trigonella suavissima Lindl.	29		
Uraria lagopodioides (L.) D. Don (*lagopoides*)	6		
Vigna lanceolata Benth.	*		
V. marina (Burm.) Merr. (*V. retusa* Walp.)	1, 2, 30	C, (C, Lu, P, B, T)	1, 2, 30
V. vexillata (L.) Benth.	28, 30	(C, P, B, T)	30
Viminaria juncea (Schrad.) Hoffmgg. (*V. denudata* Sm.)	18		
Zornia diphylla (L.) Pers.	*		

* *See* footnote to Table 1.
† *See* footnote to Table 1.

(Received for publication Feb. 2, 1956).

TECHNICAL NOTES.
RESPONSES OF TROPICAL LEGUMES TO INOCULATION.

In the 1953–54 summer season a screening trial of Rhizobium isolates for tropical legumes was planted at Coolum, in the wallum-heath soils of Queensland. This country abounds in native legumes. Those few which have been studied to any extent are recognised as belonging to the cowpea miscellany with respect to cross-inoculation, as do the species used in the trial with the exception of *Glycine max* (L.) Merr.

Treatments consisted of single 11 ft. rows each 4 ft. apart, every third row being an uninoculated control.

The area had a preplanting dressing of dolomite applied at the rate of 2 tons per acre and a fertilizer containing superphosphate, muriate of potash and trace elements.

Prior to inoculation the seeds were surfaced sterilized with 95 per cent. ethyl alcohol for 1 min., followed by 0·1 per cent. mercuric chloride for 10 min., then washed in four changes of sterile distilled water over a period of 20 min. This method has been found very satisfactory in this laboratory.

No measurable differences in plant growth were obtained with *Vigna sinensis* (L.) Endl. ex Hassk., *Phaseolus lathyroides* L., and *Stylosanthes gracilis* H.B.K. Uninoculated plants of these species bore effective nodules as judged by the presence of haemoglobin. Results with other hosts are summarized in Table 1.

Table 1.

Response of Tropical Legumes to Inoculation.

Host.	Strain of Inoculum.	Green Yield 11 ft. row. (g.)	Crude Protein. (%)	Presence of Nodules.*
Glycine max	QA 372	700		+
	Control	238		—
Glycine javanica	QA 595	496		+
	Control	25		—
Pueraria phaseoloides	QA 548 b.	2,950	19·4	+
	Control	1,589	14·7	—
Centrosema pubescens	QA 522	2,096	16·7	+
	Control	1,334	10·5	—
Clitoria ternatea	QA 553	2,497	19·5	+
	Control	140	13·5	—
Indigofera hirsuta	QA 468	4,254		+
	Control	3,178		+

* All observed nodulation was effective as judged by the presence of haemoglobin.

The best inoculated treatment is compared with the yield for the adjacent uninoculated row. Green weights only were obtained. Crude protein values for three of the species were determined in the Department's Chemical Laboratory. Protein analyses of *Glycine max*, *G. javanica* L., and *Indigofera hirsuta* L. were not made. With the first two, colour differences were obvious, the uninoculated plants being yellow and the inoculated a deep green. All *Indigofera hirsuta* plants were a deep green.

The fact that all plants of *Phaseolus lathyroides*, *Vigna sinensis*, *Stylosanthes gracilis* and *Indigofera hirsuta* nodulated reflects the presence of naturally occurring legume bacteria for these hosts throughout the trial area. A degree of specificity of *Glycine max*, *G. javanica*, *Pueraria phaseoloides* (Roxb.) Benth., *Centrosema pubescens* Benth., and *Clitoria ternatea* L. is indicated.

In these trials and others, the only nodule pattern observed with *Stylosanthes gracilis* and *S. sundaica* Taub. has been one of numerous pin-head sized nodules scattered over the entire root system. These have been effective as judged by the plant response and by the presence of haemoglobin, although usually at any one time numerous green non-functional nodules can be observed.

G. D. BOWEN,
Plant Pathology Section.

TOMATO MITE CONTROL.

The cosmopolitan tomato mite (*Vasates lycopersici* (Massee) : Eriophyidae) (see Lamb 1953) has been known as a pest in Queensland for many years. First recorded by Tryon (1917), it was later discussed briefly by Veitch and Simmonds (1929), and in more detail by Veitch (1938), Sloan (1941, 1945), Officers of the Department of Agriculture and Stock (1951) and Smith (1955).

This mite has a State-wide distribution on tomato (*Lycopersicon esculentum* Mill.), and is a major pest in the crop, particularly in districts from Rockhampton north. Other hosts are potato (*Solanum tuberosum* L.), Cape gooseberry (*Physalis peruviana* L.), wild gooseberry (*Physalis minima* L.) and blackberry nightshade (*Solanum nigrum* L.). More recently (7–11–55) a major pest of tobacco in the Texas-Yelarbon-Inglewood region has been identified by the Commonwealth Institute of Entomology as *Vasates* sp. nr. *lycopersici* (Massee).

On September 18, 1951 an exploratory field trial (6 x 4 randomised block, with plot size of 4 adjacent plants of Bowen Globe) was set out in the Bowen district to evalute chemicals and control schedules against *V. lycopersici*. Mite counts were made on November 13, using the following method :—Two leaflets, each about 1·25 sq. in., were taken from the base of the fourth leaf from a terminal on each plant. The 8-leaf plot sample was placed in formalin for 24 hours, the formalin and water washings then being filtered by suction through black filter paper marked in eight equal sectors. The mites on one sector were counted. Details of treatments and results as pest survival on November 13 are given in Table 1.

Table 1.

Results of Exploratory Field Trial.

Treatment.*	Treatment Rate (Active).†	Frequency of Treatment.	Transformed Mean. ($\sqrt{x + \frac{1}{2}}$.)
Parathion (E605) spray (0·02% active)	1·6–4·8 oz./ac. ..	Fortnightly	0·6
Parathion spray (0·02% active) ..	1·6–4·8 oz./ac. ..	Weekly	0·4
Parathion spray (0·01% active) ..	0·8–2·4 oz./ac. ..	Fortnightly	0·4
Sulphur spray	3·75–12·25 lb./ac.	Fortnightly	9·4
Sulphur spray	3·75–12·25 lb./ac.	Fortnightly	1·0
Sulphur dust	5–15 lb./ac. ..	In intervening weeks	
Check	..	..	27·1
Differences necessary for significance	5% ..	..	1·33
	1% ..	..	1·84

* All treatments sprayed fortnightly with DDT (0·1%) and copper oxychloride (0·25%).

† Varied with plant size.

To improve mite counts within plots, the following method was used during 1954. Mites were counted until at least 160 were scored, or until those in all sectors had been used, which ever occurred first. Final results were adjusted and expressed as the numbers of mites per 8-segment equivalents (*s.e.* ± 10%).

During July a screening trial was set out using parathion as the standard against para tertiary butylphenoxyisopropyl chloroethyl sulphite ("Aramite"), para chlorophenyl para chlorobenzene sulphonate ("Ovamite" = "Ovotran" = ("Mitran"), para chlorobenzyl para chlorophenyl sulphide ["Chlorparacide"] ("Mitox"), para chlorophenyl benzene sulphanate ("Elimite"), and "Systox".

Results indicated that none of the newer materials warranted further trials against the tomato mite.

Table 2.

Results of a Typical Field Trial.

Treatment.	Frequency of Treatment.	Mites at Final Sampling.		Yield of Marketable Fruit. (Mean Weight, lb./Plot).
		Equivalent Mean.	Transformed Mean. ($\sqrt{x + \frac{1}{2}}$.)	
(*a*) Sulphur wettable powder (0·15%)	Fortnightly	0·99	1·22	94
(*b*) Sulphur dust (90% S) ..	Fortnightly, alternating with (*a*)			
Lime sulphur (0·22% polysulphide)	Fortnightly	3·26	1·94	94
Parathion (0·015% active) ..	Weekly	8·03	2·92	78
Parathion (0·015% active) ..	Fortnightly	13·94	3·80	100
Parathion (0·015% active) ..	Fortnightly	39·95	6·36	89
Check	..	858*	..	114
Differences necessary for significance { 5%	..	..	3·49	F not
1%	..	..	4·89	significant

*Obviously inferior and not included in the analysis.

The results from a typical field trial set out as a 6 x 4 randomised block with 8 plants of the variety Valiant per plot are given in Table 2. Treatments in this trial were applied over a 3-month period from July 14, a week after planting out, until a week before final harvesting. The sulphur and first two parathion treatments were used in combination with DDT wettable powder (0·1 per cent.) and copper oxychloride (0·25 per cent.). These materials were used in the intervening weeks on the lime sulphur plots, and copper oxychloride only was used with the third parathion treatment. Samples for mite counts were taken on August 5

and 18, September 2, 15 and 29, and December 11. The first occurrence of the pest in appreciable numbers was in the mid-September samples—i.e., 2–4 weeks later than usual. This delay probably accounts for the satisfactory comparative yields from check plots.

This experimental work in the Bowen district and observations on commercial control demonstrate that *Vasates lycopersici* (Massee) in tomato crops can be controlled by parathion or sulphur schedules. Taking into account local field conditions and crop, the sulphurs were recommended for use on tomatoes (Smith 1955 a) and parathion for the control of the Eriophyid and Tetranychid mites on tobacco in south-western Queensland (Smith 1955 b).

REFERENCES.

Lamb, K. P. 1953. Tomato gall mites from Morocco. Bull.Entom. Res. 44 : 401-4.

Officers of the Department of Agriculture and Stock. 1951. The Queensland Agricultural and Pastoral Handbook, Vol. III, 2nd ed. Government Printer: Brisbane.

Sloan, W. J. S. 1941. The control of tomato pests. Qd Agric. J. 56 : 277-94.

Sloan, W. J. S. 1945. The control of tomato pests. Qd Agric. J. 61 : 17-41.

Smith, W. A. 1955*a*. Control of tobacco pests. Qd Agric. J. 81 : 87-9.

Smith, W. A. 1955*b*. The tomato mite. Qd Agric. J. 81 : 90-1.

Tryon, H. 1917. Rep. Qd Dep. Agric. 1916-17. Government Printer: Brisbane.

Veitch, Robert. 1938. Insect Pests and their Control. *In* The Queensland Agricultural and Pastoral Handbook, Vol. III. Government Printer: Brisbane.

Veitch, Robert, and Simmonds, J. H. 1929. Pests and diseases of Queensland fruits and vegetables. Government Printer: Brisbane.

W. A. SMITH and G. W. SAUNDERS,
Entomology Section.

PAINTING EXPOSED ROOTS *IN SITU* FOR PHOTOGRAPHING.

A method of painting plant roots for photographing described by Hass and Rogler (1953) has been modified to suit soil conditions at the Ayr Regional Experiment Station of the Department of Agriculture and Stock.

A pit approximately 5 ft. x 4 ft. is excavated to the desired depth and the side to be photographed is scraped vertically with a spade to provide a smooth face. The area is then sprayed with water, using moderate pressure, to remove about $1\frac{1}{2}$ in. of soil and expose the roots. In the light alluvial soils, root damage by hosing is negligible.

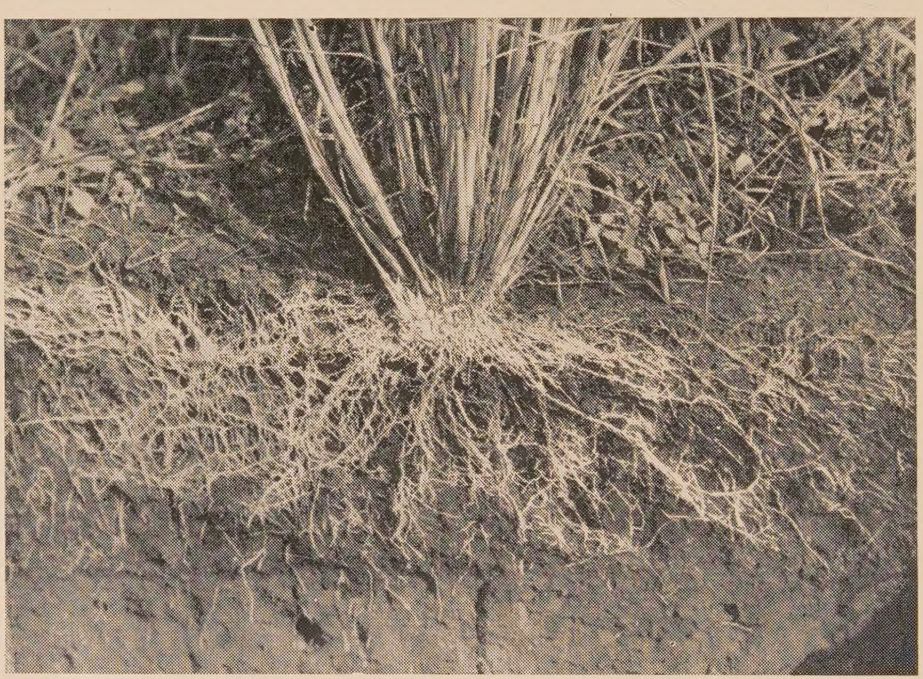


Fig. 1.

Root System of Guinea Grass Photographed After Spray-Painting.

A good white paint was tested in dilution with boiled linseed oil, acetone or white spirit. White spirit was most satisfactory. The linseed oil was too heavy and slow-drying, and the acetone dried rapidly, causing clogging of the spray and uneven distribution of the paint. The paint was applied with a continuous atomiser.

It was found that if the soil surface was allowed to dry before spraying, the paint was difficult to remove. Better results were obtained by spray-painting while the soil surface was moist and then removing the paint-covered soil. Where paint was removed from roots, the area concerned was re-sprayed.

It is desirable to photograph the roots while the soil surface is damp. Should drying occur, a light damping is recommended to provide greater contrast with the whitened roots.

REFERENCE.

HASS, H. J., and ROGLER, G. A. 1953. A technique for photographing grass roots *in situ*. Agron.J. 45:173.

W. L. PARMEIJER,
Regional Experiment Stations Branch.

A. H. TUCKER, Government Printer, Brisbane.